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Hazardous Waste Land Disposal Facilities
Public Comment Draft

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**Construction Quality Assurance
For Hazardous Waste Land Disposal Facilities
Public Comment Draft**

68-02-3992
Task 032

Project Officer

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In cooperation with

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DISCLAIMER

This report was prepared by C. M. Northeim and R. S. Truesdale of the Research Triangle Institute (RTI), Research Triangle Park, North Carolina, under Contract Number 68-02-3992, Task 032. The U.S. Environmental Protection Agency (EPA) Project Officer was J. G. Herrmann of the Hazardous Waste Engineering Research Laboratory, Cincinnati, Ohio. Substantial input and guidance were received from Les Otte of the Office of Solid Waste.

This is a draft guidance document that is being distributed by EPA for comment on the accuracy and usefulness of the information it contains. The report has received extensive technical review, but the Agency's peer and administrative review process has not yet been completed. Therefore it does not necessarily reflect the views or policies of the Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the Environmental Protection Agency; the permitting and other responsibilities of State and local governments; and the needs of both large and small businesses in handling their wastes responsibly and economically.

This guidance document, prepared in cooperation with the Office of Solid Waste, presents the elements of a construction quality assurance plan that should be addressed during the permit application procedure for a specific site. These elements include: (1) areas of responsibility and lines of authority in executing the plan; (2) requisite qualifications of the construction quality assurance personnel; (3) types of inspection activities (observations and tests) to be performed as part of the construction quality assurance activity during construction; (4) sampling requirements (including sampling frequency, size, and location; acceptance and rejection criteria; and corrective action procedures); and (5) documentation. The document discusses management of construction quality for the construction or installation of several facility components. These are foundations, dikes, low-permeability soil liners, flexible membrane liners, leachate collection systems, and cover systems.

David G. Stephan, Director
Hazardous Waste Engineering Research Laboratory

PREFACE

Subtitle C of the Resource Conservation and Recovery Act (RCRA) requires the U.S. Environmental Protection Agency (EPA) to establish a Federal hazardous waste management program. This program must ensure that hazardous wastes are handled safely from generation until final disposition. EPA issued a series of hazardous waste regulations under Subtitle C of RCRA that are published in Title 40 Code of Federal Regulations (CFR) Parts 260 through 265 and Parts 122 through 124.

Parts 264 and 265 of 40 CFR contain standards applicable to owners and operators of all facilities that treat, store, or dispose of hazardous wastes. Wastes are identified or listed as hazardous under 40 CFR Part 261. Part 264 standards are implemented through permits issued by authorized States or EPA according to 40 CFR Part 122 and Part 124 regulations. Land treatment, storage, and disposal (LTSD) regulations in 40 CFR Part 264 issued on July 26, 1982, and July 15, 1985, establish performance standards for hazardous waste landfills, surface impoundments, land treatment units, and waste piles. Part 265 standards impose minimum technology requirements on the owners/operators of certain landfills and surface impoundments.

EPA is developing three types of documents for preparers and reviewers of permit applications for hazardous waste LTSD facilities. These types include RCRA Technical Guidance Documents, Permit Guidance Manuals, and Technical Resource Documents (TRDs).

The RCRA Technical Guidance Documents present design and operating specifications or design evaluation techniques that generally comply with or demonstrate compliance with the Design and Operating Requirements and the Closure and Post-Closure Requirements of Part 264.

The Permit Guidance Manuals are being developed to describe the permit application information the Agency seeks and to provide guidance to applicants and permit writers in addressing information requirements. These manuals will include a discussion of each step in the permitting process

and a description of each set of specifications that must be considered for inclusion in the permit.

The Technical Resource Documents present summaries of state-of-the-art technologies and evaluation techniques determined by the Agency to constitute good engineering designs, practices, and procedures. They support the RCRA Technical Guidance Documents and Permit Guidance Manuals in certain areas (i.e., liners, leachate management, closure covers, and water balance) by describing current technologies and methods for designing hazardous waste facilities or for evaluating the performance of a facility design. Although emphasis is given to hazardous waste facilities, the information presented in these TRDs may be used for designing and operating nonhazardous waste LTSD facilities as well. Whereas the RCRA Technical Guidance Documents and Permit Guidance Manuals are directly related to the regulations, the information in these TRDs covers a broader perspective and should not be used to interpret the requirements of the regulations.

This Technical Guidance Document is a first edition draft being made available for public review and comment. It has undergone review by recognized experts in the technical areas covered, but Agency peer review processing has not yet been completed. Public comment is desired on the accuracy and usefulness of the information presented in this document. Comments received will be evaluated, and suggestions for improvement will be incorporated, wherever feasible, before publication of the second edition. Communications should be addressed to: Project Officer--Construction Quality Assurance, U.S. Environmental Protection Agency, Land Pollution Control Division, Room 461, 26 W. St. Clair St., Cincinnati, OH 45268. The document under discussion should be identified by title and number-- "Construction Quality Assurance for Hazardous Waste Land Disposal Facilities" (EPA/530-SW-85-021).

ABSTRACT

The U.S. Environmental Protection Agency's (EPA's) construction quality assurance (CQA) program is a two-part program established to ensure, with a reasonable degree of certainty, that a completed hazardous waste land disposal facility meets or exceeds all design criteria, plans, and specifications. The first part of this program includes regulations and guidelines that require the implementation of CQA during construction and outline recommended elements of a CQA program. The second part, addressed by this document, is guidance that addresses the site-specific components of a CQA plan. This document covers CQA for hazardous waste landfills, surface impoundments, and wastepiles. The major components of these facilities that are addressed include foundations, dikes, low-permeability soil liners, flexible membrane liners, leachate collection systems (primary and secondary), and cover systems.

The CQA plan is a site-specific document that should be submitted during the permitting process to satisfy EPA's CQA requirements. At a minimum, the CQA plan should include five elements, which are briefly summarized below.

- Responsibility and Authority--The responsibility and authority of all organizations and key personnel involved in permitting, designing, and constructing the hazardous waste land disposal facility should be described fully in the CQA plan.
- CQA Personnel Qualifications--The qualifications of the CQA officer and supporting inspection personnel should be presented in the CQA plan to demonstrate that they possess the training and experience necessary to fulfill their identified responsibilities.
- Inspection Activities--The observations and tests that will be used to monitor the installation of the hazardous waste land disposal facility components should be summarized in the CQA plan.

- Sampling Requirements--The sampling activities, sample size, sample locations, frequency of testing, acceptance and rejection criteria, and plans for implementing corrective measures as addressed in the project specifications should be presented in the CQA plan.
- Documentation--Reporting requirements for CQA activities should be described in detail in the CQA plan. This should include such items as daily summary reports, inspection data sheets, problem identification and corrective measures reports, block evaluation reports, design acceptance reports, and final documentation. Provisions for the final storage of all records also should be presented in the CQA plan.

This document describes these elements in detail and presents guidance on those activities pertaining to each of the elements that are necessary to ensure, with a reasonable degree of certainty, that a completed facility meets or exceeds all design criteria, plans, and specifications. It is intended for the use of organizations involved in permitting, designing, and constructing hazardous waste land disposal facilities, including treatment, storage, and disposal units.

This report was submitted in fulfillment of Contract No. 68-02-3992, Task 032, by the Research Triangle Institute under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period October 1984 to October 1985. Work was completed as of October 24, 1985.

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1.0 INTRODUCTION

1.1 DOCUMENT PURPOSE

This document presents guidance for preparing a site-specific construction quality assurance (CQA) plan for a hazardous waste land disposal facility (i.e., landfill, surface impoundment, or waste pile). The guidance describes the elements of a CQA program that the U.S. Environmental Protection Agency (EPA) believes are necessary to ensure, with a reasonable degree of certainty, that a completed facility meets or exceeds all design criteria, plans, and specifications.

EPA believes that a site-specific CQA plan is needed to address each of the components of a hazardous waste land disposal facility. The hazardous waste land disposal facility components discussed in this document include:

- Foundations
- Dikes
- Low-permeability soil liners
- Flexible membrane liners (FMLs)
- Leachate collection systems (LCSs)
- Final cover systems.

Development of comprehensive guidance for these components is being prepared by the Hazardous Waste Engineering Research Laboratory (HWERL) in close cooperation with the Office of Solid Waste (OSW). HWERL is using a two-phased program to meet the goals of the CQA guidance. This document is the result of Phase 1 of this program and provides currently available information on CQA for each element of a site-specific CQA plan. Phase 2 will develop comprehensive construction quality assurance guidance through a research program that will gather information on areas not addressed in detail in Phase 1.

1.2 APPLICABILITY TO MINIMUM TECHNOLOGY GUIDANCE

The Hazardous and Solid Waste Amendments of 1984 (HWSA) require that the owner/operator of an interim status hazardous waste land disposal facility who constructs a new unit, laterally expands an existing unit, or replaces an existing unit must comply with the minimum technological requirements of §3004(o) with respect to waste received after May 8, 1985. Before a permit is issued, the facility owner/operator is required to show that the liner and leachate collection systems installed during interim status were installed in good faith compliance with EPA's regulations and guidance documents.

One part of the facility owner/operator's burden of demonstrating good faith compliance is presenting evidence that the liner and leachate collection systems were designed and installed in accordance with EPA's regulations and guidance on double liner systems. The records required for making a good faith demonstration must show that the design and construction of the unit conform to the applicable regulations and guidance. As part of this demonstration, a site-specific CQA plan should be prepared and implemented, and its implementation must be adequately documented. The specific elements that should be included in the CQA plan are identified and addressed in EPA's technical guidance on double liner systems (EPA/530-SW-85-014) and are discussed in greater detail in Section 2.0 of this document.

The site-specific CQA plan and the required CQA documentation should be retained at the facility. They may be reviewed during a site inspection and will be the chief means for the facility owner/operator to demonstrate to the permit writer that EPA's technical guidance for installing a double liner system has been followed. The permit writer should expect the facility owner/operator to make this demonstration at the time of permit review, which may be some time after the units have been lined and are in use. Therefore, it is important that the owner/operator prepare a CQA plan that clearly demonstrates that he followed the EPA technical guidance on double liner systems when installing the liners and leachate collection systems.

1.3 DOCUMENT USERS

This document is intended for use by organizations involved in permitting, designing, and constructing hazardous waste land disposal facilities.

Permitting agencies (i.e., State agencies and the U.S. Environmental Protection Agency) may use this document when reviewing site-specific CQA plans to help establish the completeness of a submitted CQA plan and to ensure its implementation. This document also may be used by facility owner/operators to make certain that all aspects of CQA are covered in their permit applications by helping them critically review a site-specific CQA plan prepared by their supporting organizations (i.e., design engineer, CQA personnel, construction contractor).

Design engineers hired by the facility owner/operator may use this document as a guide in preparing a site-specific CQA plan. It also may enable design engineers to identify weaknesses and confirm strengths in their own standard CQA programs for hazardous waste land disposal facilities. CQA personnel may use this document as a convenient reference and aid in administering site-specific CQA plans. Construction contractors also may use this document as a reference that outlines the inspection activities to which their work may be subjected or as guidance for implementing their own construction quality control programs.

1.4 KEY CONCEPTS

1.4.1 Management of Construction Quality

The management of construction quality is the responsibility of the facility owner/operator and involves using scientific and engineering principles and practices to ensure, with a reasonable degree of certainty, that a constructed hazardous waste land disposal facility meets or exceeds all design criteria, plans, and specifications. This management activity begins during the design of the facility, continues throughout construction, and ends when the completed facility is accepted by the owner/operator.

Construction quality management comprises both a planned system of inspection activities that are necessary to monitor and control the quality of a construction project and a planned system of overview activities that

provide assurance that these inspection activities are being properly performed and documented and that the resulting data are properly interpreted. For hazardous waste land disposal facilities, CQA may involve verifications, audits, and evaluations of the factors that affect the installation, inspection, and performance of the facility to ensure, with a reasonable degree of certainty, that the facility meets or exceeds the specified design.

1.4.2 Construction Quality Assurance Program

The CQA program discussed in this document is EPA's approach to CQA for hazardous waste land disposal facilities. This program is divided into two parts: (1) regulations/guidelines that specify the use of CQA during construction and outline the elements of the CQA program, and (2) guidance that addresses the elements of a site-specific CQA plan. This document is the result of one phase of the second part of EPA's CQA program.

1.4.3 Construction Quality Assurance Plan

This document provides guidance for preparing a CQA plan--the facility owner/operator's site-specific written response to EPA's CQA program. The purpose of this plan is to ensure, with a reasonable degree of certainty, that a completed facility meets or exceeds all design criteria, plans, and specifications. Although CQA is, by definition, a system of overview activities, the CQA plan also must include a detailed description of the inspection activities that will be used to monitor and control construction quality.

The CQA plan documents the owner/operator's commitment to CQA and should be tailored to the specific facility to be constructed. The facility owner/operator's CQA plan should be included in the permit application. The permitting agency should review the plan for completeness and confirm that it is implemented.

1.5 DOCUMENT SCOPE AND LIMITATIONS

This document is a compilation of information on construction quality assurance and is limited in its scope and function in the following ways. First, although the document provides information on state-of-the-art CQA

for hazardous waste land disposal facilities, it is not necessarily comprehensive. Researching and evaluating all possible sources of effective CQA guidance and procedures were beyond the scope of, and outside the time frame available for, this effort. Second, this document should not be construed to present design procedures for hazardous waste land disposal facilities. That remains the responsibility of the design engineer and should be based on site-specific conditions.

2.0 ELEMENTS OF A CONSTRUCTION QUALITY ASSURANCE PLAN

The facility owner/operator should prepare a written CQA plan as part of the permit application. Although the overall content of the CQA plan will depend on the site-specific nature of the proposed hazardous waste land disposal facility, at a minimum several specific elements should be included in the plan. These elements are summarized briefly below.

- Responsibility and Authority--The responsibility and authority of all organizations and key personnel involved in permitting, designing, and constructing the hazardous waste land disposal facility should be described fully in the CQA plan.
- CQA Personnel Qualifications--The qualifications of the CQA officer and supporting inspection personnel should be presented in the CQA plan to demonstrate that they possess the training and experience necessary to fulfill their identified responsibilities.
- Inspection Activities--The observations and tests that will be used to monitor the installation of the hazardous waste land disposal facility components should be summarized in the CQA plan.
- Sampling Requirements--The sampling activities, sample size, sample locations, frequency of testing, acceptance and rejection criteria, and plans for implementing corrective measures as addressed in the project specifications should be presented in the CQA plan.
- Documentation--Reporting requirements for CQA activities should be described in detail in the CQA plan. This should include such items as daily summary reports, inspection data sheets, problem identification and corrective measures reports, block evaluation reports, design acceptance reports, and final documentation. Provisions for the final storage of all records also should be presented in the CQA plan.

Each of these elements is described in greater detail in the following subsections.

2.1 RESPONSIBILITY AND AUTHORITY

2.1.1 Organizations Involved in CQA

The principal organizations involved in permitting, designing, and constructing a hazardous waste land disposal facility include the permitting agency, facility owner/operator, design engineer(s), CQA personnel, and construction contractor(s). Except for the permitting agency, the principal parties will not necessarily be independent of each other: the facility owner/operator also may be the construction contractor; the design engineer also may be the construction contractor; the CQA personnel may be employees of the facility owner/operator, of the design engineer, or of an independent firm. Regardless of the relationships among the parties, it is essential that the areas of responsibility and lines of authority for each party be clearly established as the first element of the CQA plan. For example, it is very important that the CQA officer be at the same authority level as the construction superintendent and not be responsible to him or her. This will help establish the necessary lines of communication that will facilitate an effective decisionmaking process during implementation of the site-specific CQA plan.

2.1.1.1 Permitting Agency--

The permitting agency (i.e., State agencies and U.S. Environmental Protection Agency) is authorized by law and regulation to issue a permit for the construction and operation of a hazardous waste land disposal facility. It is the responsibility of the permitting agency to review the facility owner/operator's permit application, including the site-specific CQA plan, for compliance with the agency's requirements (i.e., regulations) and to write a permit or deny the application based on this review. The agency will have the responsibility and authority to review and accept or reject any design revisions or requests for variance that are submitted by the facility owner/operator after the permit is written. The agency also may review CQA records during or after facility construction to confirm, with a reasonable degree of certainty, that the facility was constructed so that it meets or exceeds all design criteria, plans, and specifications.

2.1.1.2 Facility Owner/Operator--

The facility owner/operator is responsible for the design, construction, and operation of the hazardous waste land disposal facility. This responsibility includes complying with the requirements of the permitting agency in order to obtain a permit and assuring the agency, by the submission of CQA documentation, that the facility was constructed, with a reasonable degree of certainty, to meet or exceed all design plans, criteria, and specifications. The owner/operator has the authority to select and dismiss parties charged with design, CQA, and construction activities. The owner/operator also has the authority to accept or reject design plans and specifications, CQA plans, progress reviews and recommendations of the CQA officer, and the materials and workmanship of the contractor.

2.1.1.3 Design Engineer--

The design engineer's primary responsibility is to design a hazardous waste land disposal facility that fulfills the needs of the facility owner/operator in terms of facility function and that meets the requirements of the facility owner/operator's submittal to the permitting agency. Design activities do not end until the facility is completed; the design engineer may have to change some design elements if unexpected site conditions are encountered or changes in construction methodology occur that could adversely affect facility performance. CQA provides assurance that these unexpected changes or conditions will be detected, documented, and corrected during construction.

Additional responsibility and authority may be delegated to the design engineer by the expressed consent (i.e., a contractual agreement) of the facility owner/operator. Additional responsibility and authority may include formulating and implementing a site-specific CQA plan, periodic review of CQA documentation data sheets and reports, modifying construction site activity, and specifying corrective measures in cases where deviation from the specified design or failure to meet design criteria, plans, and specifications is detected by the CQA personnel.

2.1.1.4 CQA Personnel--

The overall responsibility of the CQA personnel is to perform those activities specified in the CQA plan. At a minimum, CQA personnel should

include a CQA officer and the necessary supporting inspection staff. The specific responsibilities and authority of each of these individuals should be defined clearly in the CQA plan and associated contractual agreements with the facility owner/operator. For the CQA officer, specific responsibilities may include:

- Reviewing design drawings and specifications for clarity and completeness
- Serving as the owner/operator's or design engineer's liaison with the construction contractor in interpreting and clarifying project drawings and specifications
- Educating construction and inspection personnel on job requirements
- Scheduling site inspections
- Directing and supporting the inspection staff in performing observations and tests by:
 - submitting blind samples (knowns and blanks) for analysis by the inspection staff and one or more independent laboratories
 - confirming that the testing equipment, personnel, and procedures do not change over time or making sure that any changes do not result in a deterioration of the inspection process
 - confirming that the test data are accurately recorded and maintained (this may involve selecting reported results and backtracking them to the original handwritten log and laboratory data sheets)
 - verifying that the raw data are properly summarized and interpreted
- Providing to the facility owner/operator reports on the inspection results including:
 - reviews and interpretations of observation records and test results
 - identification of work that the CQA officer believes should be accepted, rejected, or uncovered for observation, or that may require special testing, inspection, or approval

- reports that reject defective work and specify corrective measures
- Verifying that the contractor's construction quality control plan is being followed.

For the supporting inspection staff, specific responsibilities may include:

- Verifying that the equipment used in testing meets the test requirements and that the tests are conducted by qualified personnel according to the standardized procedures defined by the CQA plan
- Monitoring all tests conducted by the contractor's personnel as may be required by the contract and/or the design specifications
- Performing independent onsite inspection of the work in progress to assess compliance by the contractor with the facility design criteria, plans, and specifications
- Reporting to the contractor results of all observations and tests as the work progresses and interacting with the contractor to provide assistance in modifying the materials and work to comply with the specified design
- Reporting to the CQA officer results of all inspections including work that is not of acceptable quality or fails to meet the specified design.

2.1.1.5 Construction Contractor--

It is the responsibility of the construction contractor to construct the hazardous waste land disposal facility in strict accordance with design criteria, plans, and specifications, using the necessary construction procedures and techniques. This responsibility may be expanded, as part of the contractual agreement with the facility owner/operator, to include formulating and implementing a plan for construction quality control as an adjunct to the CQA plan. The construction contractor has the authority to direct and manage his employees and the equipment they use to accomplish the construction.

2.1.2 Project Meetings

Periodic meetings held during the life of the project will enhance the responsibility and authority associated with permitting, designing, and

constructing a hazardous waste land disposal facility. Conducting periodic project meetings is the responsibility of the facility owner/operator; he may delegate that responsibility to one of his supporting organizations (e.g., design engineer). Regardless of who conducts them, periodic project meetings benefit all those involved with the facility by ensuring familiarity with facility design, construction procedures, and any design changes. The types of meetings that may be held are discussed in the following subsections.

2.1.2.1 Resolution Meeting--

A meeting should be held to resolve any uncertainties following the completion of the design criteria, plans, and specifications and the site-specific CQA plan for the facility. The facility owner/operator, design engineer, and CQA officer should all be present. The purpose of this meeting is to:

- Provide each organization with all relevant documents and supporting information
- Review the design criteria, plans, and specifications
- Review the CQA plan
- Make any appropriate modifications to the design criteria, plans, and specifications so that the fulfillment of all design specifications or performance standards can be determined through the implementation of the site-specific CQA plan
- Make any appropriate modifications to the CQA plan to ensure that it specifies all CQA activities that are necessary to determine if design criteria, plans, and specifications can be measured.

The meeting should be documented by a designated person, and minutes should be transmitted to all parties.

2.1.2.2 Preconstruction Meeting--

A preconstruction meeting should be held at the site. At a minimum, the meeting should be attended by the design engineer, the CQA personnel, and the construction contractor(s). The purpose of the preconstruction meeting is to:

- Review the responsibilities of each organization

- Review lines of authority and communication for each organization
- Discuss the established protocol for observations and tests
- Discuss the established protocol for handling construction deficiencies, repairs, and retesting
- Review methods for documenting and reporting inspection data
- Review methods for distributing and storing documents and reports
- Review work area security and safety protocol
- Discuss any appropriate modifications of the construction quality assurance plan to ensure that site-specific considerations are addressed
- Discuss procedures for the protection of materials and for the prevention of damage from inclement weather or other adverse events
- Conduct a site walk-around to verify that the design criteria, plans, and specifications are understood and to review material and equipment storage locations.

The meeting should be documented by a designated person and minutes should be transmitted to all parties.

2.1.2.3 Progress Meetings--

A progress meeting should be held daily at the work area just prior to commencement of work. At a minimum, the meeting should be attended by the construction contractor(s) and the CQA personnel. The purpose of the meeting is to:

- Review the previous day's activities and accomplishments
- Review the work location and activities for the day
- Identify the contractor's personnel and equipment assignments for the day
- Discuss any potential construction problems.

This meeting should be documented by a member of the inspection staff.

2.1.2.4 Problem or Work Deficiency Meetings--

A special meeting may be held when and if a problem or deficiency is present or likely to occur. At a minimum, the meeting should be attended by the construction contractor(s) and the inspection staff. The CQA officer should attend those meetings that include discussions of severe or recurring problems. The purpose of the meeting is to define and resolve the problem or recurring work deficiency in the following manner:

- Define and discuss the problem or deficiency
- Review alternative solutions
- Implement a plan to resolve the problem or deficiency.

The meeting should be documented by a member of the inspection staff.

2.2 PERSONNEL QUALIFICATIONS

The construction quality assurance plan should include a specific section that presents the CQA officer and the inspection staff assigned to the project (identifying them by name if possible), documenting their education and experience and describing their expected duties.

Hazardous waste land disposal facilities are uniquely engineered structures designed primarily to contain toxic or noxious chemical compounds. Therefore, it is critical that day-to-day CQA activities are oriented to ensure, with a reasonable degree of certainty, that the completed facility meets or exceeds the design criteria, plans, and specifications. This requirement may demand that the CQA officer, inspection staff, and any consultants use techniques or ensure that techniques are used that are different both in concept and performance from inspection activities routinely accepted in civil or military construction.

2.2.1 CQA Officer

The CQA officer is that individual assigned singular responsibility for all aspects of the construction quality assurance plan. The CQA officer is responsible to the facility owner/operator and should be independent of jurisdiction from the construction contractor(s). The location of the CQA officer within the overall organizational structure of the project, including the facility owner/operator, design engineer, construction contractor, and

permitting agencies, should be clearly described within the CQA plan as noted in the previous discussion on responsibility and authority.

The CQA officer should possess adequate formal academic training in engineering, engineering geology, or closely associated disciplines and sufficient practical, technical, and managerial experience to successfully oversee and implement construction quality assurance activities for hazardous waste facilities. Since the CQA officer will be expected to interrelate with all levels of personnel involved in the project, good communication skills are essential. The CQA officer should be expected to ensure that communication of all CQA-related matters is conveyed to and acted upon by the affected organizations.

2.2.2 Inspection Staff

The inspection staff should possess adequate formal training and sufficient practical technical and administrative experience to execute and record inspection activities successfully. This should include demonstrated knowledge of specific field practices relating to construction techniques used for hazardous waste land disposal facilities, all codes and regulations concerning material and equipment installation, observation and testing procedures, equipment, documentation procedures, and site safety.

2.2.3 Consultants

Authorities in engineering geology, geotechnical engineering, geology, soil science, chemistry, and other technical disciplines may be called in from external organizations in the event of unusual site conditions or test results. The CQA plan should prescribe detailed documentation when expert technical judgments are obtained and used as a basis for decision in some aspect of construction or design compromise. Consultants should not be employed as a substitute for objective data collection and interpretation when suitable tests are available.

2.3 INSPECTION ACTIVITIES

The third element of the CQA plan should describe the inspection activities (observations and tests) that will be performed during hazardous waste land disposal facility construction. The scope of this discussion

should cover only the construction of the facility. It is assumed that the site has been characterized adequately, including evaluation of the hydro-geologic environment. It is also assumed that a site-specific facility design has been prepared that is acceptable to the facility owner/operator and that it has been evaluated to ensure its technical correctness and feasibility.

The objective of inspection by the CQA personnel during construction is to determine whether the properties, composition, and performance of materials or installed components are within the limits established by the design specifications. Inspection may include evaluating the quality and assembly of materials and evaluating performance under specified test conditions.

This section addresses the inspection activities that are necessary to ensure, with a reasonable degree of certainty, that the completed facility meets the design criteria, plans, and specifications. The first subsection addresses general preconstruction activities applicable to all facility components. The subsequent subsections address each facility component separately and are further subdivided into sections on preconstruction, construction, and postconstruction inspection activities unique to each component. Specific test methods that may be used to inspect the components of a hazardous waste land disposal facility are listed and referenced in Appendix A.

2.3.1 General Preconstruction Activities

The CQA officer should review the design drawings and specifications for the hazardous waste land disposal facility to be constructed. The design criteria, plans, and specifications need to be understandable to both the CQA personnel and the construction contractor. If the design is deemed unclear by the CQA officer, it should be returned to the design engineer for clarification or modification.

Before construction, the CQA officer, with the assistance of the inspection staff, should assess the capabilities of the construction contractor's personnel to determine the type and amount of instruction, training, and supervision needed during all phases of construction. The contractor's prior performance in general construction activities, experience in con-

structing hazardous waste land disposal facilities, and experience in working with the specific materials and equipment to be used in constructing the facility should be addressed in this assessment. The CQA officer also may want to evaluate the contractor's ability to perform a specific task before task performance during facility construction. The evaluation should include the performing of specific tasks under the same environmental conditions and using the same equipment and procedures specified in the design.

It may be necessary to include a preconstruction training program in the site-specific CQA plan. As stated by the U.S. Department of the Army's Construction Control for Earth and Rock-Fill Dams (1977):

Preconstruction instructions and training should be given to field inspection personnel to acquaint them with design concepts and to provide them with a clear understanding of expected conditions, methods of construction, and the scope of plans and specifications. This may be done by training sessions, preferably with design personnel present, using a manual of written instructions prepared especially for field personnel, to discuss engineering considerations involved and to explain control procedures and required results.

The ultimate decision on whether to implement a preconstruction training program rests with the facility owner/operator but may be influenced by recommendations of the supporting organizations.

2.3.2 Foundation

Foundations of hazardous waste land disposal facilities should provide structurally stable subgrades for the overlying facility components. The foundation also should provide satisfactory contact with the overlying liner or other system component. In addition, the foundation should resist settlement, compression, and uplift resulting from internal or external pressure gradients, thereby preventing distortion or rupture of overlying facility components.

It is assumed that, before construction, adequate site investigations have been conducted and the foundation design has been developed to accommodate the expected site conditions. The following subsections describe the quality assurance activities necessary to ensure, with a reasonable degree

of certainty, that a foundation meets or exceeds the specified design. Specific tests mentioned in this section are listed and referenced in Appendix A.

2.3.2.1 Preconstruction--

It is especially important for all CQA personnel and the construction contractor(s) to review site investigation information to familiarize themselves with the expected site conditions upon which the facility designs were based. This will help ensure that the CQA personnel will be able to identify any unexpected site conditions that may be encountered during foundation construction. Unexpected site conditions may necessitate modifications of the facility design and construction procedures by the design engineer and the construction contractor to ensure component performance.

2.3.2.2 Construction--

To ensure that the design objectives for the foundation are met, inspection activities during construction of the foundation should include the following (U.S. Army, 1977):

- Observations of soil and rock surfaces for adequate filling of rock joints, clay fractures, or depressions, and removal and filling of sand seams
- Measurements of the depth and slope of the excavation to ensure that it meets design requirements
- Observations to ensure proper placement of any recessed areas for collection or detection pipes and sumps
- Tests and observations to ensure the quality of compacted fill
- Observations of stripping and excavation to ensure that there are no moisture seeps and that all soft, organic, and otherwise undesirable materials are removed. Proof-rolling with heavy equipment can be used to detect soft areas likely to cause settlement. Consistency of the foundation soil may be checked with a hand penetrometer, field vane shear test, or similar device.

In addition, when the foundation is to serve as the lower bedding layer for an FML, inspection activities should include the following:

- Observations to ensure the removal of objects (e.g., roots and rocks) that could penetrate the FML
- Observations to ensure uniform application of herbicide, when specified, to the foundation soil to prevent vegetation from damaging the liner
- Observations and tests to ensure that the surface is properly compacted, smooth, uniform, and free from sudden changes in grade.

Inspection activities during foundation construction will help ensure, with a reasonable degree of certainty, that the facility meets or exceeds all design criteria, plans, and specifications by preventing, detecting, and correcting the following:

- Sidewall slope failure from moisture seeps, weak foundation soil, or sidewall slopes that are steeper than specified
- Puddling or ponding on the foundation base, improper functioning of the leachate collection systems (LCS) resulting from less than specified bottom slopes, and the unspecified placement of recesses for LCS pipes and sumps
- Flexible membrane liner damage from an improperly prepared foundation (e.g., removing penetrating objects and sterilizing the soil)
- Foundation settlement due to soft areas in the foundation base. Excessive differential settlement can result in distortion or rupture of overlying facility components
- Regions of high permeability in the foundation base, from ungrouted joints or from the presence of high-permeability foundation materials. Permeable zones can compromise the ability of the foundation to serve as an additional barrier to leachate migration and can present pathways for seepage into the facility, causing blowout of the liner during subsequent facility construction.

Continuous visual observation of the construction process is a major means of ensuring that the foundation is constructed to meet or exceed the specified design. Surveying will be necessary to ensure that facility dimensions, side slopes, and bottom slopes are as specified in the design. Visual-manual soil identification techniques and index property tests may be used to monitor foundation soil composition. Cohesive soil consistency may be checked in the field with a penetrometer, a hand-held vane shear

device, or other suitable field-expedient measurement device (see Appendix). These field-expedient methods give only approximate values. They are usually sufficient for construction control or site material verification, but they are not accurate or precise enough to be used for acceptance testing; standard laboratory unconfined compression tests are adequate for acceptance testing (Spigolon and Kelley, 1984). Compaction of soil backfill is controlled as described in Section 2.3.3.2.1. Further information on quality control of foundations may be found in Spigolon and Kelley (1984), USBR (1974), and U.S. Army (1977).

2.3.2.3 Postconstruction--

Foundation completion tests include testing and proof-rolling to ensure uniform foundation soil consistency, visually inspecting foundation surfaces, and surveying to check elevations, slopes, and foundation boundaries.

2.3.3 Dikes

The purpose of a dike in a hazardous waste landfill, waste pile, or surface impoundment is to function as a retaining wall, resisting the lateral forces of the stored wastes. It is the aboveground extension of the foundation, providing support to the overlying facility components. Dikes therefore must be designed, constructed, and maintained with sufficient structural stability to prevent massive failure. Dikes also can be used to separate cells for different wastes within a large landfill or surface impoundment.

Dikes may be constructed of pervious or impervious soil material. This material is compacted as necessary to a specified strength, unlike soil liner material, which is compacted for low permeability. Materials other than soil, such as ash, slag, or building rubble, may be used to construct dikes, as long as the design of the dike accommodates the particular material properties and proper installation procedures are followed. Drainage layers and structures may be included in the dike design if conditions warrant control of seepage. (Although seepage through the dike will probably be prevented by the liner system, a dike should be designed to maintain its integrity if the liner fails.)

The following subsections describe the quality assurance activities necessary to ensure, with a reasonable degree of certainty that a dike is constructed to meet or exceed the specified design. Specific tests mentioned in the following subsections are listed and referenced in Appendix A.

2.3.3.1 Preconstruction--

Preconstruction inspection activities for dikes include inspection of the prepared foundation, inspection of incoming materials, and construction of a test fill.

2.3.3.1.1 Materials inspection--Materials to be used for the dike should be inspected. It is especially important that all dike materials are uniform and as specified to ensure that no soft or structurally weak materials are included in the dike. Procedures for inspecting soil materials are discussed in Section 2.3.4.1.1.

2.3.3.1.2 Test fill construction--A test fill may be constructed to verify that the specified soil density/moisture content/compactive effort/strength relationships hold for field conditions and to determine construction equipment suitability. Test fill compaction is described in Section 2.3.4.1.2; unlike soil liner test fills, permeability tests are not necessary on dike test fills; strength tests are necessary. Tests for shear strength (e.g., undrained triaxial tests or unconfined compressive strength) are appropriate for cohesive soils. Field-expedient methods of measuring cohesive soil consistency (e.g., penetrometers or vane shear devices) may be used to estimate unconfined compressive strength for construction control purposes but are not sufficiently accurate for acceptance testing (Spigolon and Kelley, 1984).

2.3.3.1.3 Foundation preparation--Foundation soil analyses should include strength tests (e.g., unconfined compression or undrained triaxial tests); compressive strength correlations with standard penetration tests or vane shear tests may be used for construction control. If soft foundation conditions necessitate excavation and replacement of foundation soils, the excavation of the undesirable material and the placement and compaction of soil in the excavation should be closely and continuously monitored by inspection personnel. The fill material should be inspected to ensure that

it is uniform and as specified. Section 2.3.3.2.1 describes inspection procedures for compacted fill. Foundation quality control is described in Section 2.3.2.

2.3.3.2 Construction--

Dike construction involves standard earthwork construction practices. Dike construction activities may include fill placement and compaction, drainage system construction, and implementation of erosion control measures. Adequate CQA during dike construction will identify and correct problems resulting from inadequate construction methodologies or materials that could result in dike failure from slope instability, settlement, seepage problems (e.g., piping, pore pressure changes), or erosion.

2.3.3.2.1 Compacted fill construction--Compacted fill may be present in the dike core or may constitute the entire dike. Inspection activities that should be conducted during fill emplacement, conditioning, and compaction include:

- Testing of fill material characteristics (see Section 2.3.4.1.1)
- Measurement of loose lift thickness
- Observation of clod size reduction and material homogenization operations
- Testing of water content
- Observation of type of compaction equipment, number of passes, and uniformity of compaction coverage
- Testing of the density of the compacted fill
- Observation of scarification and connection between compacted fill lifts.

Inspection activities for compacted fill, including observations and specific tests, are discussed in more detail in Section 2.3.4.2.

Specifications for compaction of dikes may differ from those for low-permeability soil liners because the former are compacted for strength and the latter are compacted to achieve low permeability. CQA inspection activities are similar, however, except that permeability tests on undis-

turbed samples are not required for dikes. In addition, strength tests are more important for dikes than they are for soil liners. As with soil liners, close visual observation during all phases of construction is a critical aspect of CQA.

2.3.3.2.2 Dike shell construction--Semicompacted fill may be used to form the dike shells surrounding a compacted core. This fill is generally installed in a manner similar to that for compacted fill except that the lighter equipment used for hauling and spreading the dike material may be used to compact the shell material. As with compacted fill, uniformity of the material is very important. CQA inspection activities that should be conducted during dike shell installation include:

- Testing of fill material characteristics
- Measurement of loose lift thickness
- Testing fill water content and compacted fill density
- Observation of equipment type, number of passes, and routing
- Measurement of dike slopes.

CQA activities for dike shells should be directed toward ensuring that the shear strength and compressibility required by the design specifications are achieved.

2.3.3.2.3 Drainage systems installation--Installation procedures and equipment for dike drainage systems are similar to those for leachate collection systems. The observations and tests that are necessary to monitor the installation of drainage system components are discussed in Section 2.3.6.

2.3.3.2.4 Erosion control measures--Erosion control measures are applied to the outer slopes of dikes and may include berms and vegetative covers. Inspection activities necessary for ensuring the quality of erosion control measures are the same as those for topsoil and vegetation subcomponents of cover systems (see Sections 2.3.7.2.7 and 2.3.7.2.8).

2.3.3.3 Postconstruction--

Surveys and visual observations should be conducted to ensure that the dimensions of the completed dike are as specified. Dike slopes are the

most important items to check; if slopes are too steep they may be unstable and eventually could fail. Other items to be checked include berm width, crest width, overall height, thickness, and areal dimensions. Finally, vegetative cover, when specified, should be inspected at regular intervals after facility completion to ensure that vegetation is properly established.

2.3.4 Low-Permeability Soil Liners

The purpose of a low-permeability soil liner depends on the overall liner system design. In the cases of single liners constructed of soil or double liner systems with soil secondary liners, the soil liner's purpose is to prevent constituent migration through the soil liner. In the case of soil liners used as the lower component of a secondary composite liner, the soil component serves as a protective bedding material for the FML upper component and minimizes the rate of leakage through any breaches in the FML upper component. An objective shared by all low-permeability soil liners is to serve as long-term, structurally stable bases for all overlying materials.

It is assumed that, before construction, adequate studies have been conducted to ensure that the low-permeability soil liner can meet or exceed the specified design. These studies should include soil liner-leachate compatibility testing, laboratory soil density/moisture content/compactive effort/ permeability relationships, grain size distribution, Atterberg limits, and those determinations needed for specific designs (e.g., thickness and slope determinations for single and secondary soil liners). The following section describes the inspection activities that are necessary to ensure, with a reasonable degree of certainty, that a soil liner is constructed to meet or exceed the specified design. Specific tests mentioned in this section are listed and referenced in Appendix A.

2.3.4.1 Preconstruction--

Preconstruction CQA activities include inspection of liner materials and test fill compaction.

2.3.4.1.1 Material inspection--It is necessary to inspect all liner materials to ensure that they are uniform and as specified. Material inspection begins as a preconstruction activity and continues throughout

the liner construction period. If liner material is obtained onsite, the inspections can be accomplished as it is placed in the storage pile with unsuitable material being rejected. If liner material is obtained offsite, inspection of the soil may be conducted as it arrives at the construction site. Borrow area inspection also may be desirable to ensure that only suitable soil liner material is transported to the site. For borrow areas containing nonuniform materials, it may be necessary for an inspector to guide excavating equipment to avoid or segregate substandard soil material as it is excavated. The inspector should observe segregation operations carefully and continuously to ensure that only suitable material is retained for liner construction.

Initial inspection of the soil can be largely visual; however, the inspector must be experienced with visual-manual soil classification techniques. Changes in color or texture can be indicative of a change in soil type or soil moisture content. The soil also should be inspected for roots, stumps, and large rocks. In addition to observations, a sufficient number of samples of the liner material should be tested to ensure that material properties are within the range stated in the specifications.

Testing should include at least the following:

- Permeability
- Soil density/moisture content relationships
- Maximum clod size
- Particle size distribution
- Atterberg limits
- Natural water content
- Potential volume change
- Susceptibility to frost damage.

The number of determinations for each property depends on site-specific conditions (e.g., soil type), familiarity with the site, and the previous experience of the construction contractor. Usually a minimum number of tests per lift and per unit volume of liner material is specified, with additional tests being required by the inspector if visual observations indicate that the borrow material may have changed. See Section 2.4 for more information on sampling requirements.

2.3.4.1.2 Test fill construction--A test fill is a structure used to verify the adequacy of the materials, design, equipment, and construction procedures proposed for the soil liner. Constructing a test fill before full-scale facility construction can minimize the potential dangers and expense of constructing an unacceptable liner. In addition, the test fill is a convenient tool for evaluating the most critical performance standard of the compacted soil liner--field permeability.

The primary purpose of a test fill is to verify that the specified soil density/moisture content/permeability values can be achieved consistently in the full-scale facility with the full-scale compaction equipment and procedures. For these data to be useful, test fill compaction and testing must be well documented, and soil materials, procedures, and equipment used in the test fill must be the same as those used during construction of the full-scale facility.

Several recent studies have indicated that field permeability of a compacted soil liner may be much greater than would be predicted from laboratory permeability tests (Herzog and Morse, 1984; Gordon and Huebner, 1983; Daniel, 1984; Boutwell and Donald, 1982). Field tests have been found to be much more accurate predictors of the rate at which water will drain through a soil liner than laboratory tests. When used in conjunction with these field tests and a detailed CQA plan, a test fill allows the performance of the full-scale facility to be predicted with the highest degree of confidence currently practical.

Recently, several field infiltrometers have been developed and tested that measure very low permeability values (Day and Daniel, 1985; Anderson et al., 1984). Although it is difficult to quantify exactly field permeability values that are substantially less than 1×10^{-7} cm/s (Anderson et al., 1984), it is less difficult to verify simply that the field permeability is 1×10^{-7} cm/s or less (Day and Daniel, 1985). Such a verification would demonstrate that a soil liner meets or exceeds the EPA performance standard.

Field permeability tests conducted on the actual liner can cause substantial delays in construction and result in other problems caused by the prolonged exposure of the liner. Therefore, field permeability tests

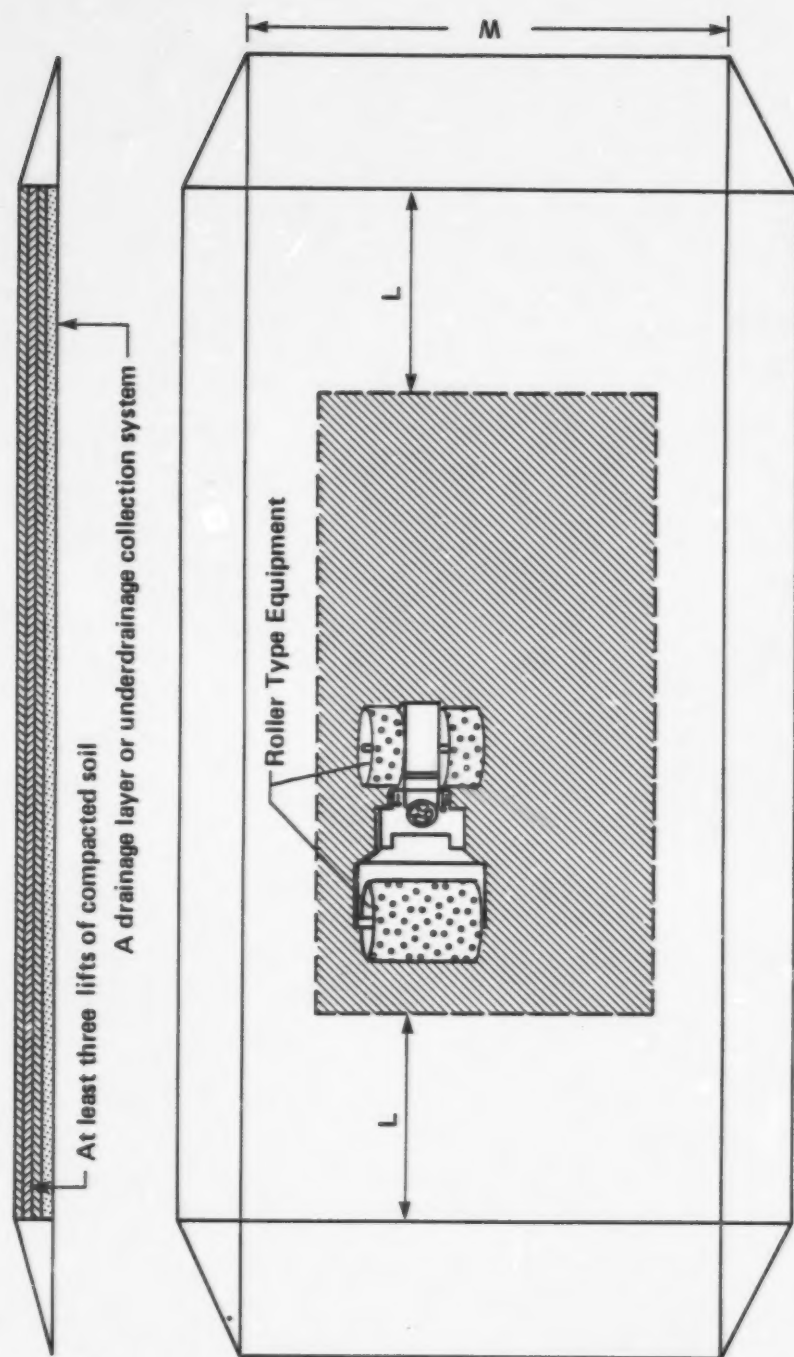
are usually conducted only on the test fill, thus making it necessary to use data obtained from detailed characterization of the test fill to reach conclusions about the permeability of the full-scale facility soil liner. Such field tests are valid only if the test fill and full-scale facility are constructed according to the same specifications and using the same methodology and equipment.

The CQA plan should describe all observations and tests to be evaluated on the test fill, including a description of the testing sample arrays and replications to be conducted. Based on the parameters evaluated and data collected from the test fill, the CQA plan should specify the tests that will be applied to the full-scale facility liner as surrogates for actual in situ permeability tests. Surrogate tests are a group of tests that do not actually measure field permeability but whose results, when considered together, can be used to estimate field permeability and hence can be used to control this parameter during low-permeability soil liner construction. If surrogates for field permeability tests are to be used with a high degree of confidence, data obtained from test fill evaluation need to show the relationships between the actual measured permeability of areas and lifts across the test fill and the proposed surrogate test results. The CQA plan should describe in detail the actual surrogate observations and tests (including, at a minimum, permeability of recompacted soil samples, Atterberg limits, particle size distribution, maximum clod size, in situ moisture content, soil density, compactive effort, and penetrometer tests) to be used to control and monitor the construction of the full-scale facility liner and the procedures to be used to relate the results of these tests to field permeability of the liner, both in the test fill and in the full-scale facility.

For the test fill to accurately represent the performance of the proposed full-scale facility, the following guidelines should be followed:

- Construction of the test fill should use the same soil material, design specifications, equipment, and procedures proposed for the full-scale facility.
- All applicable parts of the CQA plan should be followed precisely to monitor and document test fill construction and testing.

- The test fill should be constructed at least four times wider than the widest piece of construction equipment to be used on the full-scale facility (Figure 2-1). This is to ensure that there will be sufficient area to conduct all testing after a buffer area has been left along the edges of the test fill.
- The test fill should be long enough to allow construction equipment to achieve normal operating speed before reaching the area within the test fill that will be used for testing (Figure 2-1).
- The test fill should be constructed with at least three lifts to evaluate the methodology used to tie lifts together.
- The test fill should be constructed to facilitate field permeability testing (i.e., equipped with an underlying unsaturated sand layer or free-draining geotextile to collect and measure drainage through the soil liner [Figure 2-2]).
- Undisturbed samples of the test fill liner should be collected for laboratory permeability tests. Following collection of undisturbed samples from the test fill, the methodology for repairing holes in the soil liner should be evaluated. The evaluation of a repair area should include all of those tests previously identified for undisturbed portions of the test fill. The methods and materials that will be used in the repair process should be documented in the CQA plan and should be followed during repair of testing or sampling holes during full-scale liner construction. Performance of repaired soil liner sections should be equal to or exceed the performance of other liner sections.
- The test fill construction should include the removal and replacement of a portion of the soil liner to evaluate the method proposed for repair of defective portions of the full-scale liner.
- The test fill should be constructed to allow determination of the relationship of and density/moisture content/permeability values to the following:
 - the compaction equipment type, configuration, and weight
 - the number of passes of the compaction equipment
 - for sheepsfoot rollers, the drum diameter and length, empty and ballasted weight, length and face area of feet, and the yoking arrangement (U.S. Army 1977)



L = Distance required for construction equipment to reach normal operating speed
 W = Distance at least four times wider than the widest piece of construction equipment
 [Hatched Box] = Area to be used for testing

Figure 2-1. Schematic of a test fill.

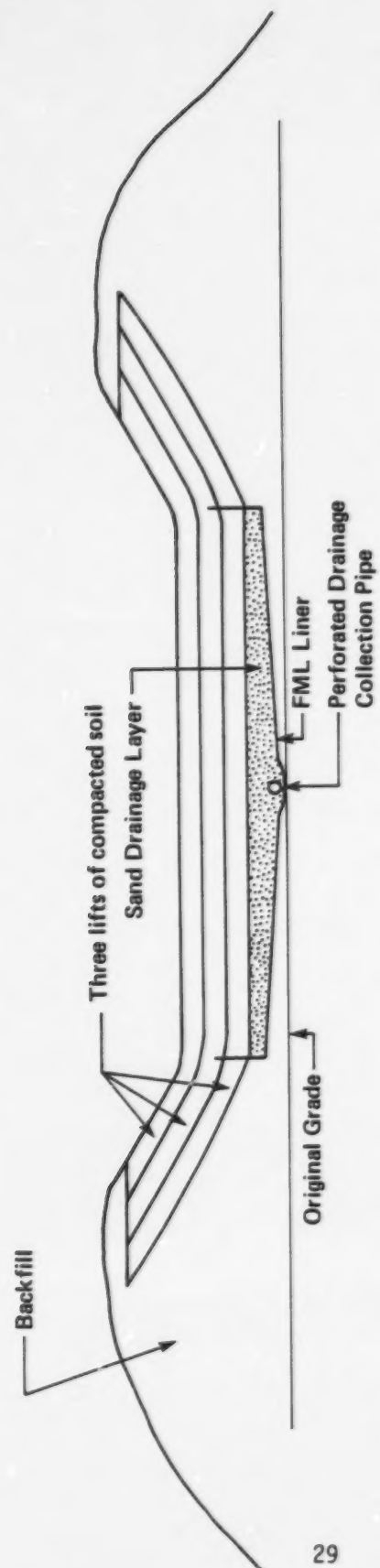


Figure 2-2. Schematic of a test fill equipped to allow quantification of underdrainage.

- for rubber-tired rollers, the tire inflation pressure, spacing of tires, and empty and ballasted wheel loads (U.S. Army 1977)
- the method used to break down clods before compaction and the maximum allowable clod size
- the method used to control and adjust moisture content, including equilibration time, and the quality of water to be used in any adjustment
- the speed of the compaction equipment traveling over the liner
- the uncompacted and compacted lift thicknesses.

Additional test fills should be constructed for each borrow source and whenever significant changes occur in the liner material, equipment, or procedures used to construct the soil liner.

The CQA officer and the inspection personnel should monitor and thoroughly document construction and testing of the test fill. Test fill documentation is extremely important because it provides all organizations involved in facility construction with a complete description of the construction equipment and procedures to be used during full-scale facility construction. For a discussion of items to be documented and documentation procedures, see Section 2.5.

2.3.4.2 Construction--

When construction of the full-scale facility liner begins, questions should not remain about either how or with what materials the liner will be constructed. The suitability of the selected liner material and the adequacy of the construction equipment, construction methodology, and testing procedures will have been confirmed in the test fill. The most important remaining task necessary to construct a soil liner that meets or exceeds the specified design will be to adhere strictly to the materials, equipment, and procedures as verified in the test fill.

There are a number of ways that improper construction practices can result in a soil liner that is unacceptable. Guidelines to identify and correct these improper practices in the field should be provided in the CQA plan. These guidelines should include a combination of both continuous

observation by an inspector during all periods and phases of liner-related construction activity and frequent use of the tests mentioned in Sections 2.3.4.1.1 and 2.3.4.1.2. Specifically, the CQA plan should address the following:

- Procedures and methods for observing and testing the soil liner materials before and after placement to ensure the following:
 - removal of roots, rocks, rubbish, or off-spec soil from the liner material
 - identification of changes in soil characteristics necessitating a change in construction specifications
 - adequate spreading of liner material to obtain complete coverage and the specified loose lift thickness
 - adequate clod size reduction of liner material
 - adequate spreading and incorporation of any certified amendments to obtain the specified amount uniformly in the amended liner material
 - adequate spreading and incorporation of water to obtain full penetration through clods and uniform distribution of the specified water content
 - procedures to be followed to adjust the soil moisture content in the event of a significant prolonged rain during construction
 - prevention of significant water loss before and after compaction.
- Procedures and methods for observing and testing the soil liner compaction process to ensure the following:
 - use of compaction equipment of the same type, configuration, and weight as used in the test fill
 - use of the same equipment speed and number of equipment passes for compaction as used in the test fill
 - uniformity of coverage by compaction equipment, especially at fill edges, in equipment turnaround areas, and at the tops and bottoms of slopes
 - consistent achievement of the specified soil density/water content/compactive effort throughout each completed lift

- consistency of permeability values obtained for undisturbed soil liner samples with values obtained for undisturbed samples from the test fill. Undisturbed sample locations should be staggered from lift to lift so holes do not align vertically.
- repair of penetrations or holes resulting from the collection of undisturbed soil samples or the use of density or moisture probes using the same materials and methods used for repairs on the test fill
- use of methods sufficient to tie liner lifts together
- achievement of sufficient liner strength to maintain stable sidewalls and to supply a stable base for supporting overlying materials
- timely placement of protective covers to prevent desiccation of liner material between the installation of lifts or after completion of the liner (where necessary)
- prevention of accidental damage of installed portions of the soil liner by equipment traffic
- achievement of the specified permeability on the soil liner sidewalls.

To ensure the above, it is necessary for the inspection staff to observe the compaction process (including estimation of compactive effort) continuously and to test the compacted liner at specified intervals using specified tests (see Sections 2.3.4.1.1 and 2.3.4.1.2). The plan for conducting these tests, including frequency and location, should be described in detail in the CQA plan. Section 2.4 discusses methods for determining sampling frequency and location as well as methods for using test data to determine whether to accept or reject a block of work. Regardless of the methods used in the development of sampling requirements, they should be clearly and completely described in the CQA plan, along with the rationale for using them. The sampling requirements also should be described on the following basis:

- Per lift and completed liner section
- Per unit volume of liner material
- Per unit surface area of a lift and completed liner section.

The compaction process is affected by climate. Construction specifications often place restrictions on work performed during and just after a rainfall, during very hot or windy conditions, or during freezing weather. For clay soil, wet or freezing weather can alter the soil water content to the point that close control of the compaction process may not be possible. Movement of the construction equipment may be severely affected. As soil temperature falls, more compactive effort must be applied to achieve the same density. Freezing can alter soil structure, causing sloughing of liner materials on the sidewalls or an increase in permeability. In very dry weather, the water content of each surface fill layer can also be altered in a very short time by drying, making continuous watering and blending necessary. Atmospheric conditions should be observed and recorded by the inspector, and appropriate actions should be taken when unsuitable weather conditions exist.

Inspection activities during the construction of low-permeability soil liners will help ensure, with a reasonable degree of certainty, that the facility meets or exceeds the design criteria, plans, and specifications by preventing, detecting, and correcting the following:

- Regions of higher-than-specified liner permeability caused by the use of unspecified materials, inadequate moisture control, insufficient compactive effort, failure to fill test holes properly, or construction during periods of freezing temperature
- Less-than-specified liner thickness or coverage from failure to observe, monitor, and control soil placement and compaction operations
- Partings between liner lifts from failure to scarify and control moisture in adjacent lifts
- Leaks around designed liner penetrations resulting from improper sealing and compaction
- Erosion or desiccation of the liner from failure to provide protective cover when construction is interrupted or after liner completion.

2.3.4.3 Postconstruction--

All observations and tests conducted on the test fill should be conducted on the completed soil liner (i.e., the uppermost lift). Immediately

before placement of any protective cover, the soil liner should be inspected for cracks, holes, defects, or any other features that may increase its field permeability. All defective areas should be removed. If the underlying foundation is defective (soft or wet), then this material also should be removed and the resultant volume should be replaced. Excavated areas of the soil liner should be repaired by the method verified during test fill construction. Special attention should be paid to the final inspections of the sidewall and bottom slopes, liner coverage, liner thickness, and the coverage and integrity of the cover placed over the liner. The completed liner should be protected from both desiccation, erosion, and freezing immediately following completion of the uppermost lift.

2.3.5 Flexible Membrane Liners

The purpose of a flexible membrane liner (FML) in a hazardous waste land disposal facility is to prevent the migration of any hazardous constituents through the liner during the period that the facility is in operation, including a 30-year postclosure monitoring period, and to allow no more than de minimis infiltration of waste constituents into the liner itself. In addition, FMLs should be resistant to the waste liquid constituents that they may encounter and be of sufficient strength and thickness to withstand the forces expected to be encountered during construction and operation.

This section describes the inspection activities necessary to ensure, with a reasonable degree of certainty, that an FML will meet or exceed all design criteria, plans, and specifications. Specific tests mentioned in this section are listed and referenced in Appendix A.

2.3.5.1 Preconstruction--

Preconstruction activities for FMLs include inspection of the raw materials, manufacturing operations, fabrication operations, and final product quality; observations related to transportation, handling, and storage of the membrane; inspection of foundation preparation; and evaluation of the personnel and equipment to be used to install the FML. These activities are discussed in the following subsections.

2.3.5.1.1 FML manufacture--Quality assurance for FML manufacture should begin with the testing of the polymer raw materials. The supplier

will generally provide documentation confirming that the raw materials comply with the manufacturers' product properties and performance requirements. However, the manufacturer and the hazardous waste land disposal facility CQA officer also should inspect the polymer raw materials. The specific observations and tests that these individuals may make, depending on the type of raw materials being supplied, include (adapted from Knipschild et al., 1979):

- Density. This property gives an indication of the material's molecular structure and degree of crystallinity, which can be related to mechanical properties such as strength and deformation.
- Melt Flow Index. The constancy of this property within narrow tolerance ranges ensures consistent molecular weight and rheological properties for high density polyethylene. Knowledge of the value for this property is also helpful when selecting production process parameters.
- Relative Solute Viscosity For Hypalon®. The value of this property indicates a polymer's mean molecular weight and its degree of polymerization. These properties affect consistency of processing and the finished product's physical properties.
- Percent Volatile Components For Hypalon®. This test gives a value for the moisture content of the raw material. It is important to control this factor to ensure that a product is free from bubbles and pores.
- Percent Carbon Black. Constant control of the amount and distribution of carbon black in the resin is important to ensure protection against UV radiation.

Additional inspections of polymer raw materials may be required by the site-specific CQA plan. These additional tests would be dependent upon the type of polymer being supplied and the environment to which it will be subjected.

Other types of raw materials that may be used in the production of specific membrane types include additives and reinforcing materials. These types of materials should be manufactured under the vendor's quality control/quality assurance program and a certification indicating that they meet the performance specifications should be provided. These additives should also be inspected to confirm that they are the materials that were requested and that they were packaged, labeled, and shipped as specified to prevent damage.

The compounding ingredients used in producing membrane liners should be first quality, virgin material meeting specific public health and safety requirements as well as providing durable and effective formulations for liner applications. Clean rework materials containing encapsulated scrim or other fibrous materials should not be used in the manufacture of FMLs. Clean rework materials of the same virgin ingredients generated from the manufacturer's own production may be used by the same manufacturer, provided that the finished products meet the product requirements.

Each manufacturer should have a manufacturing quality management program based on the manufacturing method used and the type of membrane being produced. The hazardous waste land disposal facility CQA officer should obtain a copy of and review the manufacturer's construction quality assurance program. This review should include a visit to the production plant. If there are areas where the CQA officer feels the manufacturer's construction quality assurance program is weak, he may request that the manufacturer conduct additional tests. The CQA officer may also conduct more tests to verify the manufacturer's product specifications.

The completed FML also should be tested by both the manufacturer and the hazardous waste land disposal facility CQA personnel. This phase of CQA is necessary to confirm that the final product meets the liner performance specifications. Examples of finished product specifications that may be tested for various liner types include (Eorgan, 1985; VanderVoort, 1984):

- Thickness
- Tensile properties
- Tear resistance
- Puncture resistance
- Density
- High temperature
- Low temperature
- Dimensional stability
- Resistance to soil burial
- Stress crack resistance
- Oil absorption

- Ozone resistance
- Heat aging
- Volatility loss
- Percent carbon black
- Ultraviolet (UV) resistance
- Chemical resistance
- Specific gravity
- Percent swell
- Ply adhesion
- Scrim characteristics
- Hardness.

Several of the more commonly used physical property test methods are listed in Appendix A and Section 2.3.5.2 of this document as well as in Table VIII-1, p. 407, of "Lining of Waste Impoundment and Disposal Facilities" (EPA-SW-870, 1983) and in Standard Number 54 (NSF, 1983).

To ensure that the material that was approved in the chemical compatibility test is the material that was delivered to be installed, it should be identified by an appropriate "fingerprint." (Morrison et al., 1982; Haxo, 1983; NSF, 1983.) Samples should be obtained and tested from each shipment received at the job site. The shipment should be rejected if the product is not consistent with what was originally approved.

The FML manufacturer and CQA officer should retain a sample of the finished liner from each of the raw material batches for future reference. If problems with the FML occur, it would then be easy to trace the material to the specific batch.

Some FML types require factory seaming before shipment to the construction site. This allows for smaller liner sections to be seamed into panels or blankets, which will then require fewer field seams. Blankets or panels should be assembled from roll goods according to the designer's field layout. Any changes should be approved by the designer and the owner/operator. Personnel performing the factory seaming and other duties should be under the supervision of a master seamer. The factory seam should be of equal or better quality than that described in Section 2.3.5.2.2.

Generally, seaming should be performed only when the ambient air temperature is between 40 and 100 °F and the relative humidity is less than 70 percent. However, the FML manufacturer should be consulted on recommended temperature and humidity specifications for the specific liner type. The seaming environment should be clean, and good housekeeping should be practiced.

The CQA officer should evaluate the factory seams to ensure that the seam overlap is as specified and that the proper seaming procedure was used. The seams should be 100 percent nondestructively evaluated using recommended techniques (Mitchell and Spanner, 1984). Rejected seams should be fully documented and repaired. The CQA officer should destructively test at least two factory seam samples per blanket. Samples should be taken in such a way that the blanket integrity is not damaged and the layout pattern is not altered. Repairs to the blanket should be in accordance with approved techniques and the repaired areas should be nondestructively tested to verify their integrity.

2.3.5.1.2 FML transportation and storage--FMLs are usually shipped in rolls or folded on pallets. When rolls are used, the inspector should confirm that the FML has been protected with some type of covering material; often a thick sheet of the same material as the membrane is used. When the membrane is folded on pallets, it should be placed in heavy cardboard or wooden crates before its shipment. The roll or pallet of finished materials should be marked to show the following minimum information (adapted from Schmidt, 1983):

- Name of manufacturer/fabricator
- Product type
- Product thickness
- Manufacturing batch code
- Date of manufacture
- Physical dimensions (length and width)
- Panel number or placement according to the design layout pattern

- Direction for unrolling or unfolding the membrane.

When the FML is delivered to the construction site, it should be inspected to confirm that it is the material that was specified, (i.e., fingerprinted) and that it is not damaged. Inspection activities will ensure, with a reasonable degree of certainty, that the completed facility meets or exceeds design criteria, plans, and specifications by preventing, detecting, and correcting the following:

- Puncture from nails or splinters
- Tears from operation of equipment or inadequate packaging
- Exposure to temperature extremes resulting in unusable material
- Blocking: the bonding together of adjacent membrane layers, which may be caused by excessive heat
- Crumpling or tearing from inadequate packaging support.

These types of damage may be avoided by careful handling of the FML during preparation for shipment and of the packaged crates and rolls of materials.

When damage to a crate or roll cover has occurred, careful examination of the underlying material by an inspector is required. If damage is found, the inspector should carefully examine the entire shipment for damage.

Onsite storage of the synthetic membrane liner should be in a secure area with provisions for shelter from adverse weather and be as brief as possible. This helps avoid damage caused by the following:

- UV light
- Heavy winds or precipitation
- Temperature extremes (i.e., loss of plasticizers in polyvinyl chloride [PVC], curing and adhesion of adjacent surfaces of chlorosulfonated polyethylene, and creation of permanent folds or wrinkles in certain liner types)
- Vandals.

2.3.5.1.3 Lower bedding layer placement--The observations and tests necessary to ensure that an adequate liner lower bedding layer is provided

are discussed in Section 2.3.2.2. When an FML is placed directly on the bedding layer, it is extremely important to inspect the surface visually to confirm that it is free from clods of soil, rocks, roots, sudden or sharp changes of grade, and standing water. The inspector also should confirm that the soil has been sterilized when necessary with an approved herbicide using the manufacturers' recommended procedures.

In composite liner systems, the lower FML bedding is the compacted low-permeability soil liner. If the bedding is subject to drying and cracking, precautions should be taken by the facility owner/operator to prevent desiccation. This prevention may be in the form of a temporary liner (e.g., thin plastic cover) or special nonreactive chemicals. If a temporary liner is used, the CQA officer should ensure that it is secure at the edges and that, before the installation of the designed FML, the temporary liner is removed and any soil liner cracks are documented and repaired. If desiccation cracks are observed, the appropriate techniques and specifications for correction should be provided in the design specifications.

2.3.5.2 Construction--

Failure of an FML can result from defective manufacturing and fabrication, improper handling and storage, or poor installation methods. The observations and tests necessary to detect these defects during construction are discussed in the following subsections.

2.3.5.2.1 FML placement--Inspection activities that are necessary during liner placement include (adapted from Kastman, 1984):

- Checking delivery tickets and synthetic membrane manufacturers' quality control reports to verify that the synthetic membrane rolls received onsite meet the project specifications. [In addition, "it is usually good practice to take the identifying labels from each roll or pallet and save them for future reference. Further, the position of each roll or pallet of material should be noted on a final installation drawing. This document can be used as future reference should problems occur." (Schmidt, 1983)]. As an additional check to ensure the quality of the product being delivered, a sample should be taken, "fingerprinted," and that fingerprint should be compared with the fingerprint of the product originally contracted for.
- Observations to ensure that the FML placement plan was followed.

- Observations of the weather conditions (i.e., temperature, humidity, precipitation, and wind) to ensure that they are acceptable for membrane placement and seaming.
- Observations and measurements of the anchor trench to ensure that the lines and width are as specified in the design drawings. If the trench is excavated in soil that is susceptible to desiccation, only that trench length that is required for 1 day's work should be excavated. Consideration should be given to using a temporary liner in the trench to prevent desiccation. Trench corners should be rounded to prevent stressing the membrane. Good housekeeping practices should be used in the trenching operation by not allowing any loose soil material in the trench or on the downhill side of the trench. Backfilling of the trench should be performed as soon as possible and compacted with care so as not to damage the FML.
- Observations and tests to confirm that all designed liner penetrations and liner connections are installed as specified. Liner penetrations should be verified for appropriate clamp and caulking use, for appropriate material, for good seaming, and for good housekeeping practices. No sharp bends on foundations (concrete pads) should be allowed. Soil compaction adjacent to concrete pads should be performed as specified to prevent differential settlement.
- Measurements to confirm that required overlaps of adjacent membrane sheets were achieved, that proper temporary anchorage was used (e.g., sand bags or tires), that specified temporary and final seaming materials/techniques were used, and that the blanket was placed in a relaxed (nonstressed) state.

As each synthetic membrane panel is placed, it should be visually inspected for tears, punctures, and thin spots. The inspector should also inspect any factory seams to ensure that they are adequate. To accomplish this, the panels should be traversed by the inspector in such a way that the entire surface, including all factory seams, is inspected. For synthetic membranes that are fabricated from roll stock widths of about 5 feet, the normal procedure used to detect membrane defects is to walk along each roll stock width and inspect the entire length of the sheet. Any defects should be marked on the synthetic membrane for repair.

The overall quality of a flexible membrane liner installation can be affected by the weather conditions during which it was installed. The inspector should be aware of all of these factors and the effects they may

have on the specific membrane type and seaming procedure being used. If the weather becomes unacceptable for installation of the liner, the inspector should stop the membrane installation until conditions again become favorable, thus minimizing the potential for unacceptable installation.

Inspection activities during FML placement will help ensure, with a reasonable degree of certainty, that the completed facility meets or exceeds all design criteria, plans, and specifications, by preventing, detecting, and correcting the following:

- Liner damage from adverse weather conditions, inadequate temporary anchoring, or rough handling
- Improper liner placement (if the placement plan is not followed) and, as a result, inadequate coverage with the available materials or an excess number of field seams
- Inadequate sheet overlap, possibly resulting in poor quality seams
- Nonwelded or nonseamed sections
- Inadequate seam strength.

2.3.5.2.2 FML seaming--Inspection activities that should be documented during membrane seaming operations include:

- Observations to ensure that the membrane is free from dirt, dust, and moisture
- Observations to ensure that the seaming materials and equipment are as specified.
- Observations and tests to ensure that a firm foundation is available for seaming
- Observations of weather conditions to ensure that they are acceptable for seaming
- Measurements of temperatures, pressures, and speed of seaming, when applicable, to ensure that they are as specified (gages, dials, etc., should be checked and recorded)
- Measurements of the curing time between seaming and seam testing to ensure that it is as specified
- Observations to ensure that the membrane is not damaged by equipment or personnel during the seaming process.

Inspection activities help ensure, with a reasonable degree of certainty, that the completed facility meets or exceeds all design criteria, plans, and specifications by preventing, detecting, and correcting the following:

- Seam gaps or weak spots resulting from the presence of dirt or dust
- Less-than-specified seam strength resulting from the use of unspecified materials, improperly operating equipment, insufficient pressure, ambient temperature extremes, or insufficient dwell time
- Liner damage caused by cleaning or bonding solvents and seaming equipment. Liner damage may also result from walking on the membrane while wearing improper footwear or from the improper disposal of cigarette butts.

After field seams are installed, they should be inspected to ensure that a homogeneous bond was formed. Different nondestructive inspection methods (in addition to visual observations) are available for testing seams in the field, depending on the type of liner material being placed (Mitchell and Spanner, 1984):

- Nondestructive tests should be performed on 100 percent of the field seams. Failed seams should be recorded as to location and seaming crew. The data should be reviewed for possible patterns. Repairs should be made in accordance with approved techniques and retested to verify their integrity.
- Destructive seam testing should be performed at previously agreed to locations and frequencies. A minimum number and location per seam length per seam crew should be established. If different seaming techniques are used, additional test as per seaming type should be added. Additional test locations may be necessary at the QA officer's discretion. These locations may be based on suspicion of contamination by dirt or moisture, change in seaming materials, increase in failed nondestructive tests, and other causes that could result in unacceptable seams.
- Destructive seam samples should be large enough for the installer to check in the laboratory, for an independent laboratory evaluation, and for site owner archiving. If possible the seam should be destructively tested in the field at the time of sampling (provided sufficient time has elapsed for the seam to cure properly). Proper documentation should follow each seam sample as to location, time, crew, technique, etc.

- Laboratory testing should be performed in accordance with design specifications with predetermined pass/fail values. Both peel and shear testing should be performed as suggested by Standard Number 54 (NSF, 1983) or ASTM, for the specific material type.
- For field seams that fail, the seam can either be reconstructed between the failed and any previous passed seam location or the installer can go on either side of the failed seam location (10-foot minimum), take another sample, test it and if it passes, reconstruct the seam between the two locations. If it fails, the process should be continued. In all cases acceptable seams must be bounded by two passed test locations.
- All repairs should be performed as soon as possible and in accordance with the design specifications. Each repair should be nondestructively tested for continuity. Documentation of all repairs including location, type, method used, etc., should be made.

2.3.5.2.3 Anchors and seals installation--When a hazardous waste land disposal unit design calls for penetrations (e.g., structures and pipes) in the flexible membrane liner, the inspector must ensure that the seals around such penetrations are of sufficient strength and are impermeable to leachate. Specific inspections that should be made on all seals or anchors include:

- Observations to ensure that the materials (i.e., pipe boots and sealing compounds) are compatible with the waste and are as specified.
- Observations and tests to ensure that the sealing systems (i.e., pipe boots) were installed as specified (are leak free) and in the proper locations.
- Observations to ensure that all objects that may be placed adjacent to the synthetic membrane (i.e., batten bars, soil in an anchor trench, and concrete structures) are smooth and free of objects or conditions that may damage the membrane.
- Observations and tests to ensure that all seals and anchors are complete (i.e., no gaps or areas of uncompacted backfill).

Inspection activities during this phase of construction will ensure, with a reasonable degree of certainty, that the completed facility meets or exceeds all design criteria, plans, and specifications by preventing, detecting, and correcting the following:

- Compatibility or corrosion problems from the use of unspecified materials
- Leaks around penetrations or slipping of the membrane from incomplete seals or inadequate compaction of backfill
- Flexible membrane damage from rough edges, sharp corners, or rocks. Membrane damage can also occur from excessive stress placed on the liner because of improper location of sealing and/or anchoring mechanisms.

2.3.5.2.4 Upper bedding layer placement--An upper bedding layer, often referred to as a protective cover, when required over an FML, should be placed as soon as possible after installation to protect the FML from weather conditions, equipment, and vandalism. The covering of the FML, while important and necessary, should not be performed until the FML installation is completed and accepted. However, on very large jobs, it may be necessary to have partial acceptance procedures. These can be mutually agreed upon at the preconstruction meeting. The protective cover is usually soil that is free of rocks, sticks, and other items that could damage the membrane. Inspection activities that should be conducted during protective cover installation include:

- Observations and tests to ensure that the cover material meets specifications.
- Observations to ensure that the cover material is free from objects that could damage the liner.
- Observations to ensure that the equipment or procedures used to place the cover material do not puncture or tear the synthetic membrane.
- Measurements to ensure that the entire liner is covered with the specified thickness of cover material.

There are a few standard checks and test methods that can be used, in addition to visual observations, to ensure that a flexible membrane liner's protective cover is installed according to the specified design. These checks include surveying using conventional or laser/electronic instruments to ensure that the layer thickness is as specified. The thickness of the cover layer can also be monitored simply by measuring it with a marked measuring staff. When this method is used, the inspector must ensure that

the staff does not puncture the underlying liner. The bedding layer soil type may be inspected by using visual-manual soil identification techniques and index property tests. These test procedures are briefly discussed in Section 2.3.4.1.1 and are listed and referenced in Appendix A.

Inspection activities during upper bedding layer placement will ensure, with a reasonable degree of certainty, that the completed facility meets or exceeds all design criteria, plans, and specifications by preventing, detecting, and correcting the following:

- Liner damage from the use of unspecified materials, equipment or human traffic, or weather conditions
- Insufficient upper bedding layer thickness or coverage.

2.3.5.3 Postconstruction--

Upon completion of flexible membrane liner installation and seam testing, but prior to placement of the upper bedding layer, the liner should undergo a thorough visual inspection for any damage that may have occurred during installation. If any damaged areas are located, they should be marked and patched using approved repair methods. These patched areas should be nondestructively tested to ensure that they do not leak.

To check for leaks in the installed membrane liners of small landfills or surface impoundments, the facility can be filled or partially filled with water and seepage from the site measured after accounting for evaporation. This method is often combined with leachate collection system (LCS) testing and, when feasible, is the best way to ensure that the synthetic liner will function according to specifications after it is put into service, assuming that no waste/liner compatibility problems occur. In the case of double liner systems, this type of testing will be more complex because of the presence of two LCSs.

If the waste facility shows evidence of leakage after filling with water, the leak(s) must be located, repaired, and retested before the facility can be accepted. Several techniques, including tracer dyes and electrical resistivity, could be used to locate the leak(s).

2.3.6 Leachate Collection Systems

The purpose of a primary LCS in a landfill is to minimize the leachate head on the top liner during operation and to remove liquids from the

landfill through the postclosure monitoring period. The LCS should be capable of maintaining a leachate head of less than 1 foot. The purpose of a secondary LCS (leak detection system) between the two liners of a landfill or surface impoundment is to rapidly detect, collect, and remove liquids entering the system through the postclosure monitoring period.

The following sections describe the CQA inspection activities necessary to ensure, with a reasonable degree of certainty, that a completed LCS meets or exceeds all design criteria, plans, and specifications. Specific tests referred to in the following sections are listed and referenced in Appendix A.

2.3.6.1 Preconstruction--

Preconstruction activities for a leachate collection system include inspection of all materials and examination of the LCS foundation.

2.3.6.1.1 Material inspection--Observing all LCS subcomponent materials as they are delivered to the site is necessary to confirm and document that these materials conform to the design criteria, plans, and specifications. To accomplish this, inspection activities should include the following:

- Observations to ensure that all synthetic drainage layers and/or geotextiles meet the design specifications.
- Observations and measurements to ensure that the pipes are of the specified size and strength, are constructed of the specified material, and that pipe perforations are sized and spaced as specified.
- Observations and tests to ensure that the soils to be used in the LCS are of the proper size and gradation, do not contain unspecified types of materials, and that specified provisions to keep LCS soils clean during storage, handling, and placement are followed.
- Observations to ensure that all prefabricated structures (e.g., manholes and sumps) are as specified in the design. This should include inspection of any corrosion-resistant coatings to confirm that they are present and without flaws.
- Observations of all mechanical, electrical, and monitoring equipment to ensure that it is as specified in the design. In some cases (e.g., pumps), the specific pieces of equipment can be tested to ensure that they are operational.
- Observations and tests to ensure that, when concrete structures are to be installed, the raw materials supplied and necessary forms are as specified in the design.

Testing of the soil materials includes visual-manual classification, grain size distribution tests, and permeability tests to ensure that proper soil types are used for specific applications.

2.3.6.1.2 Foundation preparation--An examination of the foundation for the leachate collection system should be performed before construction. In the case of double liner systems, the bedding for both primary and secondary leachate collection systems will be an FML or a low-permeability soil liner depending on the type of facility. Inspection activities should include:

- Measurement of the horizontal and vertical alignment of the foundation to ensure that leachate will flow toward the sump.
- Observation of the foundation to ensure that it is free of debris and liquids that would tend to interfere with construction of the leachate collection system.

2.3.6.2 Construction--

A leachate collection system is composed of many separate subcomponents. Each of these subcomponents must be installed as specified in the design to ensure proper facility function. The following subsections include discussions of observations and tests that should be performed for each leachate collection system subcomponent.

2.3.6.2.1 Bedding layer placement--To avoid damage to the foundation of the LCS, a bedding layer may be placed before pipe network installation. The bedding layer may be either a granular or manufactured material (i.e., geotextile). Inspection activities that should be performed include:

- Observation of the bedding material to ensure that it is as specified and that it does not contain objects that would damage or alter the underlying foundation
- Measurement of the thickness of the bedding layer to ensure uniformity of layer depth
- Observation of the areal coverage of the bedding layer to ensure that it is the same as that specified in the design. When manufactured materials are used, it should be verified that sheets are joined or connected as specified in the design.

These observations and tests are necessary to ensure that the materials in the bedding layer do not damage the foundation.

2.3.6.2.2 Pipe network installation--The pipe network should be placed according to the specified design. Inspection activities that should be performed during pipe placement and joining include:

- Observations and measurements to ensure that the pipes are placed at specified locations and in specified configurations
- Observations and tests to ensure that all pipes are joined together as specified
- Observations to ensure that the placement of any filter materials around the pipe proceeds as specified in the design
- Observations and tests to ensure that backfilling and compaction are completed as specified in the design and that, in the process, the pipe network is not damaged.

Adequate CQA during this phase of LCS construction will prevent, detect, and correct the following:

- Clogging of the LCS pipes or sections of the pipes from the improper installation of filter materials or from construction runoff
- Inadequate LCS function from the improper joining of pipes, from the improper placement of pipes, or from mechanical damage to the pipe network.

If the pipes are not adequately protected from fine particle accumulations during the construction phase, it may be necessary to flush the pipe network upon completion to remove sedimentation and debris and to verify that the line is open. Standard sewer cleaning equipment can be used to remove objects and debris remaining after simple flushing. If this equipment is unable to pass through the line, it may mean that a section of pipe has been crushed or displaced.

Testing of solid pressure and nonpressure LCS pipes should also be conducted to check for leaks and the structural integrity of the solid pipe network. No standardized test procedures are available to perform the test for nonpressure pipes. The American Water Works Association has developed a method for testing solid pressure pipes (AWWA, 1982).

In some cases, it may be desirable to look at the interior of the pipe to verify its alignment and to confirm that there are no obstructions or debris in the pipe. The procedure consists of pulling a television camera mounted on skids through the pipe and recording the distance from the starting point as the camera moves. The location of any problem can be found by measuring the distance from the starting point. In the case of the leachate transport pipe, this procedure can be used to identify sources of infiltration.

2.3.6.2.3 Drainage layer placement--

Granular drainage layers--Granular LCS drainage layers are constructed of clean, inorganic, free-draining, granular soils such as sand and gravel. These soils are selected before their use in the LCS on the basis of their grain size distribution.

Some or all of the soil drainage layer may be placed before or after pipe placement. To ensure the quality of this drainage layer, inspectors should:

- Test the soil to ensure that it is of the specified permeability and grain size and free from excessive amounts of fines or organic materials
- Measure the thickness and observe coverage of each drainage layer lift as it is placed in the LCS
- Observe the compaction process and test the compacted layer to ensure its adequacy
- Survey the completed layer to ensure that specified grades are obtained
- Observe that the transport of fines by runoff into the LCS is prevented by barriers or filters.

When pipe placement precedes granular soil placement, it is also necessary to monitor soil placement and compaction operations to ensure that the LCS pipes are not damaged or moved by the installation equipment.

Adequate CQA inspections during granular drainage layer placement will help ensure the integrity of the entire facility by preventing, detecting, and correcting the following:

- Areas of lower than specified drainage layer permeability resulting from the use of unspecified materials or from fines that enter and clog the system
- Less-than-specified layer thickness or coverage
- Damaged and misaligned pipes.

There are several standardized test methods that may be used to monitor the drainage layer materials, placement, and compaction. The material type should be monitored using the methods discussed in Section 2.3.6.1.1. A method for determining the permeability of the installed drainage layer, along with the previously mentioned test methods, is listed and referenced in Appendix A.

Synthetic drainage layers--There are three main types of synthetic drainage materials available for use in leachate collection systems: nets, mats, and geotextile fabrics. These synthetic drainage materials may be used alone or in combination with granular drainage layers to form the LCS for a hazardous waste land disposal facility. For more information on synthetic drainage layer design and construction, see E. C. Jordan Co. (1984).

Prior to the placement of geotextiles or synthetic drainage materials, an inspector should confirm that these materials are as specified and have not been damaged due to shipping or improper storage. Several standardized tests are available to evaluate specified properties of geotextiles. These include tensile strength, puncture or burst resistance, tear resistance, flexibility, outdoor weatherability, and short-term chemical resistance. For more information on these test methods, including discussions on their applicability, limitations, and proper interpretations, the reader is referred to Horz (1984). Appendix B of Horz (1984) also contains detailed test procedures for fabric permeability and percent open area. There are currently no published standard test methods for either of these properties. An inspector also should verify that the surface on which the synthetic drainage layer or geotextile is to be placed has been prepared properly. This may include surveying the slope or grade, inspecting material type and compaction for soils, or inspecting flexible membrane seaming and anchoring.

During the installation of a synthetic drainage layer or a geotextile, the inspector should perform the following inspection activities:

- Observations to ensure that the materials are placed according to the placement plan
- Measurements to ensure that the specified material overlap is achieved
- Observations to ensure that the material is free from wrinkles and folds
- Observations to ensure that, when specified, the edges of geotextiles are coated to prevent wicking
- Tests, when required, to ensure that seams are made according to the design specifications
- Observations to ensure that weather conditions are appropriate for placement and that the exposure of the synthetic drainage layers or geotextiles to rain and/or direct sunlight during and after installation is minimized
- Observations to ensure that the material is not damaged during the installation process
- Observations to ensure that barriers or filters are installed to prevent clogging of drainage layers from fine particles in construction runoff.

Inspection activities during synthetic drainage layer placement will help ensure, with a reasonable degree of certainty, that the completed facility meets or exceeds the design criteria, plans, and specifications by preventing, detecting, and correcting the following:

- Geotextile or synthetic drainage layer slippage resulting from improper placement or seaming
- Stress damage to the material from improper placement
- Improper material function because of wrinkles in the material, inadequate seam overlap, improperly made seams, inadequate coating of the material's edge, clogging of the material by fine particles, or damage to the material from weather conditions, human traffic, or equipment.

2.3.6.2.4 Filter layer placement--The filter layer subcomponents of an LCS may be constructed of granular soils or synthetic materials. In both cases the materials used in the filter layer are selected before construction as part of the facility design criteria, plans, and specifications.

Soil filter layers--LCS soil filter layer placement quality is checked in much the same way as that for granular drainage layers; observations and tests that should be performed and recorded include:

- Soil tests to ensure that it is of the specified grain size and free of excessive amounts of fines or organic materials
- Observations of the placement process to ensure that it is performed as specified
- Measurements of the thickness of the filter layer to ensure that it is as specified.

These observations and tests are necessary to ensure that areas of the LCS do not become blinded or clogged by fine particles infiltrating the system. If this occurs, the LCS will not function properly and leachate levels in the facility may exceed regulatory requirements.

Synthetic filter layers--Geotextiles are synthetic products specially designed to have good drainage and strength characteristics. Geotextile filter layers will retain fine material that is contained in the leachate while allowing the flow of liquids to the drainage layer and collection pipes. In this application, the geotextile protects the drainage layer and pipe system from becoming clogged.

Inspection activities that should be conducted during the placement of a geotextile filter layer include:

- Tests to ensure that the geotextile permeability and effective opening size are as specified
- Observations of geotextile placement to ensure that the specifications are followed, including coverage of all specified areas and adequate material overlap or seaming
- Observations to ensure that the completed geotextile filter layer or any other system subcomponent is not damaged during placement.

These observations and tests are necessary to ensure that the LCS does not become clogged.

2.3.6.2.5 Sumps and associated structure installation--Sumps and manholes can be manufactured offsite and delivered to the site ready for installation as part of the LCS. The design engineer will usually specify that, at a minimum, the supplier should furnish certification with appropriate documentation that the structures have been fabricated according to the design engineer's specifications. Additional inspection of precast concrete, steel, and fiberglass structures may be needed to confirm the identity and quality of manufactured structures. Inspection activities that should be performed include:

- Observations to ensure that the structures were not damaged during shipment
- Measurements to ensure that the structures are of the specified dimensions and capacity
- Observations to ensure that the structures are made of the specified materials
- Observations to ensure that any corrosion-inhibiting coatings are free from defects such as flaking, scratches, or blisters. If defects are present, manufacturers' specifications for repair should be available.

These observations and tests are necessary to ensure that LCS structures are constructed of specified materials, are of adequate size, and are not damaged. If any of these situations occur, the LCS may not function properly.

Visual observations of manhole and collection tank installation are necessary to ensure that the components are installed as specified in the design and that they are not damaged during the process. Installation of the footings or foundations for these structures also should be observed to ensure that damage to the liner is prevented. Surveying should be performed to confirm that all structures are installed in the proper locations.

In the event that manufactured structures are not appropriate, cast-in-place concrete structures may be constructed. The installation of concrete structures, such as manholes and collection tanks, requires visual inspection of the installation, including cast-in-place procedures, and

tests of the concrete that is cast at the LCS site. Observations that should be made include:

- Inspection of formwork to ensure that it is complete and has the specified dimensions
- Inspection of concrete placement operations
- Inspection of the curing process to ensure that a satisfactory moisture content and favorable temperature are maintained.

These inspection activities are necessary to ensure that the resulting structure is of the specified size and strength.

Design specifications for concrete will usually require testing of the type, quality, and gradation of the aggregates; the consistency and air content of fresh concrete; and specimens of the concrete for strength. Grain size distribution tests and visual-manual classification are usually required for the aggregates before their use. Consistency, or slump, of the concrete should be determined to ensure that it conforms with the design specifications. The air content of the freshly mixed concrete can be determined by the pressure method. The compressive strength of samples of concrete can be determined using the strength test.

2.3.6.2.6 Mechanical and electrical equipment installation--Installation of mechanical equipment such as pumps, valves, motors, liquid-level monitors, and flowmeters is usually the final activity during LCS construction. The CQA inspections that should be performed include:

- Observations of all mechanical equipment installation to ensure that it is in accordance with the design specifications and manufacturer's recommendations
- Testing of all mechanical equipment in accordance with manufacturers' instructions and operations manuals. Authorized service representatives of the manufacturers may be present to provide any necessary assistance.

These observations and tests are necessary to ensure, with a reasonable degree of certainty, that the facility meets or exceeds all design criteria, plans, and specifications. This will reduce the possibility of equipment failure and leachate head buildup in the LCS.

Inspection of electrical connections for mechanical equipment should be performed by personnel certified by national and/or State licensing agencies to perform electrical work. The visual observations necessary for electrical equipment are the same as those previously discussed for mechanical and monitoring equipment. CQA testing should focus on four major areas: insulation, grounding, equipment, and control circuits.

2.3.6.3 Postconstruction--

Postconstruction inspection of a leachate collection system should include:

- Observations to ensure that all system subcomponents have been installed in the proper locations and according to design and manufacturer's specifications
- Testing to ensure that all pumps operate at rated capacity and that all electrical controls and monitoring equipment perform in accordance with the specified design.

A final performance test for a leachate collection system may be included as part of a facility's CQA plan. This test may be conducted by filling all or a portion of the system with a known quantity of water. The water should then be removed from the system and its volume determined. The volume of water remaining is the system's storage volume. If the storage volume is significantly higher than expected, there may be areas of the system that are not draining properly. If this is the case, the entire LCS should be inspected to locate the areas that are not draining properly. Corrective measures should then be implemented to ensure that specified LCS drainage can be obtained.

2.3.7 Final Cover Systems

Final cover systems for hazardous waste land disposal facilities are designed to provide long-term minimization of liquid migration and leachate formation in the closed landfill by preventing the infiltration of surface water into the facility for many years and minimizing it thereafter in the absence of damage. Final cover systems are constructed in layers, the most important of which are the barrier layers. Other layers are included to protect or to enhance the performance of the barrier layers.

The purpose of a final cover system is to provide long-term minimization of migration of liquids through the closed landfill, control the venting of gas generated in the facility, and isolate the wastes from the surface environment. A final cover system must be constructed so that it functions with minimum maintenance, promotes drainage and minimizes erosion or abrasion of the cover, accommodates settlement and subsidence so that the cover's integrity is maintained, and has a permeability less than or equal to the permeability of the bottom liner system component with the lowest permeability.

The following subsections describe the quality assurance activities necessary to ensure, with a reasonable degree of certainty, that a completed final cover system meets or exceeds all design criteria, plans, and specifications. Specific tests mentioned in this section are listed and referenced in Appendix A.

2.3.7.1 Preconstruction--

Preconstruction activities for final cover systems include screening incoming materials for the system subcomponents and compacting test fills for the soil barriers. These and other preconstruction activities for each cover system component are identified below and described in the following sections:

- Low-permeability soil barrier (Section 2.3.4.1)
- Flexible membrane barrier (Section 2.3.5.1)
- Drainage and venting layers (Section 2.3.6.1).

For the topsoil and vegetation components, it should be verified that sufficient quantities of topsoil, fertilizer, soil conditioners, and seeds are available to complete the topsoil/vegetation cover, and that the quality of these materials is as specified in the design. Topsoil should be characterized for the required agronomic properties (Gilman et al., 1983).

Before facility closure, it may be desirable to plant experimental plots to verify that the proposed vegetation will be tolerant of the expected conditions in the final cover system. Conditions that should be considered include local climate as well as (Gilman et al., 1983):

- Cover soil type, depth, and compaction

- Waste depth, type, age, and compaction
- Surface slope.

2.3.7.2 Construction--

The inspection activities necessary for evaluating the quality of a final cover system construction are addressed below by component, beginning with the final cover foundation layer. Many of the activities are the same as for other facility components addressed earlier; e.g., the low-permeability barrier is much the same as the low-permeability soil liner. Inspection activities are referenced to earlier sections as appropriate.

2.3.7.2.1 Final cover system foundation preparation--Before the construction of the cover foundation layer or overlying cover components, observation and tests should include an evaluation of the waste placement records and the actual waste placement process, where possible. This evaluation should include an estimate of the degree and uniformity of waste placement and compaction. In the case of drummed waste, the evaluation should ensure that drums are placed in an orderly manner and that voids between drums are backfilled completely. The objective is to ensure maximum and uniform compaction of the waste to minimize void spaces and to ensure that the final cover system foundation (waste) has the specified bearing strength. This is necessary to minimize the potential for future differential settlement or subsidence and resultant final cover system damage.

Soil materials to be used in the foundation should be observed and tested as necessary to confirm that they meet the specified design. Materials specifications may include a maximum grain size and a requirement that they be free of large objects that could damage or make the placement of the overlying low-permeability soil barrier difficult. The construction materials of any subcomponents that are to be installed with their bases in waste or in the foundation layer (e.g., gas vents) should be inspected for conformance to design specifications.

The construction of the final cover system foundation should be tested to determine thickness, surface slope, density, particle size, and permeability. Design requirements may be more restrictive around standpipes, vent pipes, and the perimeter of the fill area. In the perimeter area, the cover subcomponents must join the liner subcomponents through a relatively

complex design. The CQA officer should be especially cognizant of the perimeter design requirements and the measurements necessary to ensure that these requirements are met.

2.3.7.2.2 Low-permeability soil barrier placement--The low-permeability soil barrier provides a base for the flexible membrane barrier subcomponent of the final cover system and provides long-term minimization of liquid infiltration. It serves as a secondary barrier to infiltration in case the flexible membrane barrier fails.

Before construction of the low-permeability soil barrier subcomponent of the cover system, soil materials should be tested to ensure that they are as specified in the design. Throughout the construction process, testing of incoming soil materials should be done on a per-unit-volume basis, and more frequently when the inspector suspects a change in soil properties.

The low-permeability soil barrier is constructed very much like the low-permeability soil liner. Before installation of the soil barrier, a test fill should be constructed with the same materials, equipment, and procedures to be used for constructing the soil barrier to ensure that the required permeabilities can actually be achieved in the field and to determine the relationship between soil density/moisture content/compactive effort/permeability achieved in the test fill (see Section 2.3.4.1.2). This same relationship then must be obtained during the construction of the low-permeability soil barrier subcomponent. As with compacted low-permeability soil liners, it is necessary to monitor soil type, moisture content, density, compactive effort, lift thickness, clod size, uniformity of compaction, completeness of coverage, and permeability. A more complete discussion of inspection activities for low-permeability soil liners can be found in Section 2.3.4.

Seals around penetrations such as gas vent pipes and LCS standpipes should be tested to ensure that they do not leak. Compaction of the soil around penetrations should be closely observed and clod size, especially where soil is compacted using hand compactors, must be carefully controlled. It is especially important to inspect the perimeter of the cover, where the low-permeability soil barrier subcomponent joins or overlies the liner system, to ensure that it is installed to conform to the specified design.

After completion of the low-permeability soil barrier subcomponent, the surface slope of the barrier layer should be surveyed to ensure that it is constructed as designed and that no depressions remain into which water will flow and stand. In addition, the soil layer should be inspected to ensure that it provides a suitable base for the overlying flexible membrane barrier.

2.3.7.2.3 Flexible membrane barrier installation--The flexible membrane barrier prevents infiltration of precipitation through the cover and into the underlying waste.

Before installation of the flexible membrane barrier, the membrane materials should be observed and tested to ensure that they are as specified (see Section 2.3.5.1). Field seaming equipment and materials should be examined to ensure that they are as specified in the design and are adequate to do the job. Any other materials, such as hardware for anchoring and sealing the membrane to penetrating objects, should be checked for adherence to design specifications.

The base for the flexible membrane barrier subcomponent (the low-permeability soil barrier subcomponent) should be inspected before membrane installation to ensure that its surface is as smooth as possible and that there are no objects that might damage or penetrate the membrane.

All observations and tests used for FML installation are pertinent to the installation of the flexible membrane barrier final cover system subcomponent. A discussion of inspection activities for flexible membrane liners is presented in Section 2.3.5. CQA personnel should be especially attentive to the vent and standpipe penetrations to ensure the integrity of the connections bonding them to the membrane. Around the perimeter of the final cover system, where it joins the liner system, the installed flexible membrane barrier should be tested to ensure that it is installed to conform to the specified design since this is an area with a relatively high potential for leakage.

2.3.7.2.4 Bedding layer placement--An upper bedding layer may be placed to act as a protective buffer between the flexible membrane barrier subcomponent and the overlying drainage layer. This layer acts to protect the membrane from possible puncture by coarse drainage system materials.

Bedding layers may be either a granular material or a synthetic material such as a geotextile. Specific observations and tests to be performed are listed in Section 2.3.5.2.4.

Perhaps the most critical inspection activity during the placement of a bedding layer on top of a flexible membrane is to observe the placement process closely to ensure that the construction equipment does not damage the membrane. Following installation, the surface slope of the bedding layer should be surveyed to ensure that the design slope is achieved.

2.3.7.2.5 Drainage and gas venting layer placement--The drainage layers in a final cover system are designed to conduct away infiltrating precipitation before it can penetrate the barrier layers and to vent gas from the facility to appropriate treatment or collection facilities. The gas discharge layer has a consistency and configuration similar to that of the water drainage layer. Both layer types function to transmit fluid preferentially. The main distinction between them is their position in the cover system. The gas discharge layer is placed below the flexible membrane and low-permeability soil barriers and intercepts gases rising from waste cells and directs them to controlled gas discharge vents. The water drainage layer is located above the barriers to intercept and drain water percolating from the surface and direct it to the runoff control system. Both the gas venting and water drainage layers in a final cover system are similar in design and construction to the leachate collection system and may be composed of granular soils and/or geotextiles. See Section 2.3.6.2.3 for a more detailed description of drainage layers.

Current regulations require controlled discharge (collection and/or treatment) of hazardous or nuisance gases from facilities. Controlled discharge of gases accumulating in the facility is necessary because of the potential harm that toxic and/or malodorous gas may have on human health and the environment. The gas may be collected at the discharge point and transported for treatment or incineration. Alternatively, devices for removing harmful components from the gas or incinerating the harmful components in place may be devised and installed at gas discharge points. This document does not cover these devices in further detail, as currently there is no guidance for designing or constructing them.

The materials used in the construction of the drainage or venting layer are likely to have restrictive specifications, whether materials are soil or synthetic materials. Preconstruction activities must include an inspection of those materials to make certain that they meet the design specifications. The inspection should continue through the construction period as long as materials continue to be delivered to the site. Other preconstruction activities include inspection of the base for the drainage or gas venting layer to ensure that it is and remains in the condition that was specified in the design. Any protrusions, such as vents and standpipes, should also be inspected for any deviations from design specifications.

The inspection procedures during the construction of the drainage and gas venting layers are much the same as those used in the construction of the leachate collection system at the bottom of the landfill. Those procedures are addressed in detail in Section 2.3.6.2. Inspection activities will include ensuring that the specified thickness and surface slope are achieved and that grain size and hydraulic (or gas) conductivity are as specified in the design. Observations should be made of the filling process around vents and standpipes to prevent damage or misalignment of those structures.

Inspection of the installation of the drainage layers around the perimeter of the cover system is particularly important, for it is here that the system connects to the surface drainage facilities. It is especially important to ensure that the design specifications, particularly dimensions and slopes, are achieved. In addition, controlled gas discharge or collection systems should be checked for proper installation and function.

2.3.7.2.6 Filter layer placement--The purpose of a filter layer above (or below) a drainage layer is to stop the migration or piping of fine materials that could plug a drainage layer and render it ineffective. The filter layer can be constructed of soil materials or may be a geotextile. Soil layer specifications include grain size range and dry density. Geotextiles are specified according to granular equivalency.

Inspection activities prior to the construction or installation of the filter layer include inspection of the filter materials to confirm that they meet the design specifications.

During the construction of the filter layer, inspection activities will include monitoring of the grain size (for soil materials) or geotextile type and certification, uniformity of thickness for soil, seaming or overlap for geotextiles, slope of the surface, and coverage (particularly around the perimeter of the cover system). The inspector should be particularly aware of the potential for damage to penetrating objects such as vent pipes during the construction process. The perimeter area, where the drainage layer intersects surface drainage, should be closely inspected for adherence to the design specifications. More information on CQA inspection activities for filter layer placement is found in Section 2.3.6.2.4.

2.3.7.2.7 Topsoil layer placement--The topsoil layer is the uppermost component of the cover system. Its functions are to protect the underlying layers from mechanical and frost damage, and (in conjunction with a vegetative cover) to protect against erosion.

Topsoil specifications are likely to include properties (e.g., nutrient and organic content) not required for the other soil components of the facility. Soil specifications typical of the other earthwork components may also be included, however.

Preconstruction inspection activities will include checking topsoil properties against the design specifications and ensuring that deleterious materials are not included. The foundation for the topsoil layer will be the filter layer above the drainage layer. The filter layer should be checked to ensure that it has been constructed to meet or exceed the specified design and that any specified penetrations are intact and properly oriented.

During construction of the topsoil layer, the inspector should monitor the uniformity of the application process, observe the placement procedure to ensure that the soil is not overly compacted, and measure the thickness and slope of the topsoil layer. The inspector should also ensure that care is taken in the vicinity of vents or other protrusions to prevent damage by construction equipment.

2.3.7.2.8 Topsoil seeding--Topsoil placement, preparation for seeding, and the seeding may take place in a more or less continuous operation. Inspection before the seeding process should include confirmation that the

soil additives and seed are as specified in the design. Tilling depth should be measured, and the application rate of additives should be monitored to confirm that it is as specified in the design. The slope of the final surface of the cover should also be verified to ensure that it meets the design requirement. The inspector should verify that all vents and standpipes or any other penetrations through the cover are not damaged by the tilling and additive application processes.

The seeding method is also likely to be specified in the design, and the inspector should ensure that the application equipment is appropriate for the job; e.g., if hydromulching is called for, then hydromulching equipment should be available and used. The rate of seed and mulch application, amount and uniformity of coverage, and watering instructions should be followed carefully. Perimeter areas should be examined to ensure that bare spots are not left inadvertently. If tacked mulch is used, the operation should be observed to ensure that it is as specified.

Timing of seeding is important, particularly for grasses. The inspector should ensure that it occurs during the designated period and that the weather is favorable. For example, seeding should not take place during high wind or rain or when the soil is frozen. Description of the inspection activities that should be conducted during final cover system seeding may be found in Gilham et al. (1983).

2.3.7.3 Postconstruction--

The inspector should make a visual check of the completed cover to ensure that it meets the specified design. Slopes should be surveyed, any unusual depressions should be noted and corrected, and the vents and standpipes should be examined for alignment and orientation. The perimeter configuration, including drainage conduits also should be examined for conformance to design specifications.

Inspection of the cover should continue until it is ascertained that a vegetation cover has, in fact, been reasonably well established. Grass and ground cover should be evaluated once a month by a qualified specialist during the first 4 to 6 months following germination (Gilman et al., 1983). At that time a final check should be made of the final cover to ensure that it is as specified.

2.4 SAMPLING REQUIREMENTS

The fourth element of a CQA plan describes the sampling requirements for evaluating construction quality. Sampling requirements for construction materials and processes for the various components of a hazardous waste land disposal facility should include the following:

- Size of the Unit (or Block) to be Sampled. A unit or block is a definite isolated quantity of material or construction work, constant in composition and produced by a uniform process, that is presented for inspection and acceptance as a unit (Section 2.4.1).
- Number of Sample Items or Measurements per Inspection Block. The number may be established by the designer or CQA officer on the basis of judgment or by statistical methods (Sections 2.4.3.1 and 2.4.3.2).
- Location(s) of Sample Items or Measurements. Locations for individual observations or for sampling may be established by the designer or CQA officer on the basis of judgment or statistical methods (Sections 2.4.2.1 and 2.4.2.2).
- Acceptance Criteria. The determination of natural process variabilities, levels of confidence, and acceptance criteria for each characteristic are all design functions, involving site-specific requirements and engineering experience, skill, and judgment. Acceptance criteria should reflect the type of sampling plan (judgment or statistical) that is employed (Section 2.4.2). The design specifications, acceptance/rejection criteria, and sampling methods must be consistent and closely coordinated by the design engineer in the design report and CQA plan.
- Treatment of Outliers. Criteria for identifying and rejecting outlying test results may be established based on confidence level requirements (statistical sampling methods only) or based on the judgment of the CQA officer (Section 2.4.4).
- Corrective Measures to be Taken in the Event of Noncompliance. When a quantity of work or material is rejected, it must be reworked to bring it up to specification or replaced by acceptable work (Section 2.4.5). The actual physical means of correction in the case of noncompliance is a combined design and construction operations function; this topic is beyond the scope of a CQA document.

For many materials or construction processes, it is necessary to estimate the quality of the overall material or process from the observed

or measured quality of a representative sample that is a small fraction of the total material or process. Examples of these situations include assessment of characteristics of a soil liner (permeability, moisture content, density, grain size), testing chemical compatibility of an FML, and destructive testing of FML seams. This section provides general guidance for selection and implementation of an appropriate sampling scheme and specifies what constitutes a sample item, how the items will be selected, and the number of items to be selected.

2.4.1 Definitions of Sampling Terms

The term block, as used herein, refers to a definite, isolated quantity of material, such as soil, of constant composition and produced by essentially the same process, that is presented for inspection and acceptance. Alternatively, it may be a unit of construction work that is assumed to have been produced by a uniform process. It is characteristic of a block that all variation among measured properties within it is random, or is assumed to be random, with no underlying differences between locations in the block. Therefore, the block can be characterized by a block mean and a block variance for each quality characteristic.

Block size is established on the basis of judgment of uniformity of materials and/or workmanship and on economics of inspection. Generally, materials and/or workmanship close together in time or space will be more similar than elements far apart. A block may be any unit presented for quality evaluation and acceptance. This may be a single day's production, a portion of a day's work, a stockpile of material from a uniform, well-defined source, or a single shipment of offsite material.

For sampling purposes, a block is usually subdivided into a number of batches of sample units, each a small and easily identified length, area, volume, weight, package, or time period. A batch is a discrete unit or subdivision of a block of material, such as a package or roll of geomembrane, a truck load of sand or portland cement, or a length of drain tile. A sample unit is an arbitrary subdivision, in time or space, of a block of material or workmanship. A lift of compacted fill, a length of membrane seam, or an exposed face of trench wall may be subdivided in some rational fashion.

A sample item is that portion of material removed (or tested in place) from each selected batch or sample unit. A sample is a collection of sample items, such as test bores, truck loads, grid sections, or sections of an FML seam. Each item in the sample is independent from the other items in the sample and data are collected for each sample item. The sample may represent a block of construction material, a block of construction processing, or an incoming shipment of offsite material for the purpose of inspection as a basis for judging, or estimating, the quality of the block.

2.4.2 Sampling Strategies

The establishment of sampling methods and of sampling and testing frequency may be based on either judgment or experience or on probabilistic methods using statistical theory (Deming, 1950). Willenbrock (1976) states that, up until the last 10 to 15 years ". . . quality of construction was largely accomplished through semi-artisan techniques and procedures with constant visual inspection," or in other words, judgment sampling. Judgment methods were, and still are, subject to biases and sampling errors (Deming, 1950) dependent on the knowledge, capability, and experience of the specification writers, the inspection staff, and the CQA officer. These factors cannot be easily evaluated and documented. Methods using statistical theory are more rational, calculable, and documentable than judgmental methods and are recommended where feasible and applicable. Whether judgmental or statistical sampling is to be used, it is imperative that the procedure to be used is clearly and completely specified in the CQA plan and is an accepted approach to sampling the construction materials or operations being evaluated. The rationale used to select and develop the sampling approach should be explained in the CQA plan.

2.4.2.1 100-Percent Sampling--

The ideal situation is that where the quality of all of the material used for a particular component of a hazardous waste land disposal facility can be assessed by an objective observation or test procedure. Clearly these procedures are limited to observations and nondestructive tests that are relatively inexpensive in terms of resource and time requirements.

Examples of such methods are those tests used for FML seams and anchors, collection system pipe joints, pump function, electrical connections, and final leak detection (filling a facility with water). A less than optimum, but necessary, situation is where the quality of a material is assessed by subjective evaluation (usually visual inspection) of all of the material.

2.4.2.2 Judgment Sampling--

Judgment sampling refers to any sampling program where decisions concerning sample size, selection scheme, and/or locations are based on other than probabilistic considerations. The objective may be to select typical sample elements to represent a whole process or to identify zones of suspected poor quality. Sampling frequency is often specified by the designer and may be a function of the confidence he has in the CQA personnel. Selection of the sampling location(s) is often left up to the inspector or CQA officer making the entire process dependent on the validity of his judgment.

There can be no standardized rules for judgment sampling simply because such sampling depends on the judgment of the designer, CQA official, and/or inspection staff. Because judgment sampling plans are based on the experience and opinions of the CQA personnel, sample estimates (e.g., mean, variance, or relationship among variables) may be biased and hence may not accurately represent the overall material or process. There is no way to test for or to quantify these inherent biases nor to estimate the level of confidence associated with the sample estimates. For example, with a judgment sampling scheme, it is not possible to estimate how closely the quality measurement of the sample approximates that of the overall material or process with a specified level of confidence.

2.4.2.3 Statistical Sampling--

There is an inherent, or natural, variability in measurement data for any specified quality characteristic of most materials and components used in construction (Terzaghi and Peck, 1967), including the materials and processes used to construct a hazardous waste land disposal facility. This variability may be attributed to variability in material quality, construction operations, measurement techniques and instrumentation, as well as the

overall capabilities of the inspection staff. There is a need for formalized statistical sampling methods to estimate or describe the overall quality of the individual facility components and for an assessment of the variability in test results that might occur if multiple independent samples were collected.

Statistical sampling methods are based on the principles of probability theory and are used to estimate selected characteristics (e.g., mean, variance, percent defective, relationships) of the overall material or process (population). The primary differences between these methods and those based on judgment are that sample selection is by an objective process that reduces the likelihood of selection bias (i.e., every sampling unit has a known likelihood of selection) and provides a means of assessing the magnitude of potential error in the sample estimate(s) (i.e., variability in sample estimates that would be observed if multiple independent samples were selected or the likelihood that the sample estimate does not deviate from the overall characteristic to be estimated by more than some specified amount).

In statistical sampling, a sample unit refers to entities that are enumerated for purposes of sample selection and may or may not be the items that are measured. For example, if a grid is overlaid on a soil liner and grid sections are selected into the sample, the grid sections are the sample units; a single measurement, such as size, might be performed for each grid section or a sample of smaller units (e.g., core sections) might be selected from each grid section for testing. The underlying requirement for a statistical (or random) sample is that all of the units selected into the sample must have a known probability (chance) of selection into the sample. An example of a common approach is to assign a unique serial number to each potential sampling unit in the overall material or process and select serial numbers by some random process such as drawing numbers from a hat or using a random number table.

There are many variations in random sampling plans that can be used. Some examples are:

- If the soil to be used to line a hazardous waste land disposal facility is known to be different in one area of the borrow source from another, independent samples might be selected from each area and the results combined by a weighting

scheme depending on some property of the differentiating characteristic such as grain size, consistency, or overall density (stratified sampling).

- If it is impractical to enumerate all possible sample items (or points), it may be possible to select a small number of large sample units and then select a sample of measurable elements from each unit. The previously mentioned example of selecting core sections from a sample of grid sections of a soil liner illustrates this type of sampling (two-stage sampling plan).
- If many loads of soil are being hauled to a site and it is reasonable to assume that the loads are homogeneous relative to a particular characteristic, it may be desirable to examine every n th load after starting with a randomly selected start less than ' n ' (systematic sampling).
- If the goal is to assess some characteristic of a compacted soil lift, it may be desirable to overlay the site with a grid pattern and to select grid sections for sampling by randomly selecting coordinates. In this situation, if each section has an equal chance of selection, the plan would be classified as simple random sampling. If instead the plan specified that the selection probabilities be in proportion to some known characteristic such as area of grid section, it would be classified as a proportionate sampling. For example, if some grid sections are twice as large as others, the large sections could be given twice the probability of selection as the small sections. The primary caution is that selection probabilities be known in advance or be equal for all units in an area and that an accepted statistical technique be used for selection of random numbers. It is not satisfactory to use some other means of selecting sample units such as picking numbers from the air.

The plan used for each evaluation should be tailored to the particular situation and types of sample estimates desired. If the goal is to estimate some characteristic of a completed component or process, a simple random sample design or some modification such as a stratified or two stage sampling plan should be used. If the goal is to monitor an ongoing operation such as placement of soils by trucks, a systematic sampling plan may be used, where every n th truck would be examined after a random start. The reason for this selection is that the latter design does not require complete enumeration of the potential sampling units whereas some such enumeration scheme is usually necessary for the other designs. Once the data have been

collected from a particular sampling plan they must be summarized, analyzed, and presented in a way that is tailored to the sample design that was used.

Since all of the sampling designs are based on the principles of simple random sampling, the remaining discussion will be limited to these designs. For more information concerning the available sampling designs or their underlying probability and distributional properties and assumptions, see Kish (1967).

2.4.3 Selection of Sample Size

The sample size is the number of sample items whose test outcomes are combined mathematically to yield sample parameters. Sample size may be selected by judgment or statistical methods. The judgment method is subjective, based solely on intuition. Classical statistical methods are based on sample-derived statistics and on judgment-selected confidence levels.

2.4.3.1 Judgment Method--

The judgment method depends almost entirely on the intuition of the specifier, presumably based on engineering and materials evaluation experience. All of the comments made earlier, in Section 2.4.2, regarding sampling methods also apply to sample size selection. Judgment methods result in sample means, sample variances, and variable relationships that may be biased and, therefore, may not accurately represent the overall material or processes. These biases cannot be quantified; thus the level of confidence associated with sample estimates cannot be estimated for judgment sampling schemes.

Testing frequency for judgment sampling schemes is often set to produce a fixed proportion of the population (such as 10 percent) or to yield a prespecified sample size per specified unit of time, distance, area, or volume (e.g., taking samples of FML seams on a per linear foot basis). The sample proportions or sizes are usually established on the basis of judgment and experience from similar construction projects. Sampling schemes are usually used to specify minimum sampling frequencies. These frequencies can be increased to identify potential problem areas where additional tests should be made. Samples ideally should be located where the inspector has reason to doubt the quality of materials or workmanship.

Organizations that construct large numbers of similar projects, such as the U.S. Army Corps of Engineers or the U.S. Bureau of Reclamation, often employ judgment sampling with sampling frequencies based on knowledge from their years of construction experience. Usually a range of sampling frequencies is suggested, with estimates of site- and material-specific variability determining which end of the range to use initially. Table 2-1 lists test frequencies used by various organizations for earthwork construction.

Other examples of sampling plans can be found in standard specifications such as AASHTO (1983) and ASTM (1985b), particularly for sampling and testing of materials. The sampling of a batch, such as a soil stockpile, in which some segregation may have naturally occurred, often involves taking three or more sample items that are blended into a single representative element for analysis.

2.4.3.2 Statistical Methods--

A statistically rational and valid method for selecting sample size is given in ASTM (1985b) E 122-72. The equation for the number of sample units (sample size, n) to include in a sample in order to estimate, with a prescribed precision, the average of some characteristic of a block is:

$$n = (ts/E)^2 \quad (2.1)$$

or, in terms of coefficient of variation

$$n = (tV/e)^2 \quad (2.2)$$

where

n = number of units in the sample

t = probability factor

s = the known or estimated true value of the standard deviation for the overall material or process to be estimated

E = the maximum allowable error between the estimate to be made from the sample and the result of measuring (by the same methods) all of the units in the overall material or process

$e = E/\bar{X}$, the allowable sampling error expressed as a percent (or fraction) of $\bar{X}$

TABLE 2-1. MOISTURE/DENSITY TEST FREQUENCY RECOMMENDATIONS
FOR EARTHWORK QUALITY CONTROL

	USBR ^a	U.S. Navy ^b	U.S. Army ^c
Mass earthworks (embankments, dikes)	1 per 2,000 yd ³	1 per 500 yd ³	1 per 1,000 to 3,000 yd ³
Earth linings	1 per 1,000 yd ³	1 per 500 to 1,000 yd ³	--
Hand-tamped backfill	1 per 200 yd ³	1 per 100 to 200 yd ³	--
Minimum per shift (mass earthwork)	1	1	--
Doubtful areas (inspector's discretion)	1	1	--
Pervious materials	1 per 1,000 to 10,000 yd ³	--	--

^aUSBR (1974).

^bU.S. Department of the Navy (1982).

^cU.S. Department of the Army (1977).

$\bar{X}$ = the expected (mean) value of the characteristic being measured

V = coefficient of variation.

The probability factor, t, in equations (2.1) and (2.2) is the standard normal deviate (see ASTM, 1985b, for description) that corresponds to the chosen level of confidence that the sample estimate will not differ from the true value of the "to be estimated" characteristic for the overall material or process by more than the allowable error (E). For a two-sided test (test for error both above and below the estimated value), the commonly used values of t are 1.96 or 1.64, corresponding to 95 and 90 percent levels of confidence, respectively. For a one-sided test (test for error in one direction only), a value of 1.64 corresponding to the 95 percent level is commonly used. For values of t (or z, as indicated in many tables and texts) corresponding to other levels of confidence, see any basic statistics book.

As described in ASTM (1985b) E 122-72, the estimated standard deviation, s, should be derived from previous measurements of standard deviation for the same material or process, and should have been developed from at least 30 measurements. As new data are collected from subunits of the overall material or process, they can be used to supplement or replace the old data (depending on comparability of the new and old data) to further refine the estimate of s and the resulting sample size estimate. If no previous data exist, s can be roughly approximated from background knowledge of the shape of the distribution or by conducting a pilot, or preliminary, study where a small number of measurements are performed on a subset of the overall material or process (possibly on the test fills).

It should be recognized that a sample size determination is an estimate (or best guess) of the minimum quantity sufficient to satisfy stated objectives. Since the estimates are based on historical data or subjective opinions of the underlying distribution and cannot take into account all of the factors that contribute to sample variability, they may not be adequate to produce assessments with the prespecified level of confidence. It is always necessary to recompute confidence levels as part of the ordinary data analysis of the sample data. If the resultant confidence level is not sufficient, it may be necessary or at least desirable to supplement the

sample to attain the desired level. As long as the original sample was selected by an accepted random process, the test methods have not changed since the initial sample analysis, and the same sampling scheme used for the original sample is used for the supplement (i.e., every sample unit has an equal likelihood of inclusion in either the original or supplemental samples), it usually will be satisfactory to combine the two samples to reduce variability of the sample estimates and hence increase the confidence level. It is not acceptable to use sample supplementation in an attempt to change sample estimates (such as means) to make them more acceptable.

A sample size designed to produce estimates with prespecified reliability or confidence for the overall material or process probably will not be adequate to assess the quality of some subsection where there is a need for separate evaluation. For example, the sample size selected for determining whether the overall clay liner meets the maximum criteria for permeability probably will not be sufficient to assess the permeability of a particular section of the liner where the soil appears to differ from that used in the rest of liner. Therefore it may be necessary to increase the sample frequency or sample size for a subarea where visual observations of materials or construction operations indicate that the quality of construction is suspect. If these data are to be combined with the rest of the data from the overall site, all data analyses must include an adjustment for the differences in sample selection probabilities between the two samples.

2.4.3.2.1 Acceptance sampling--For some characteristics, such as flexible membrane liner strength or soil permeability, a limit of acceptability (e.g., permeability less than 10^{-7} cm/s) can be specified. If the standard deviation of the characteristic can be estimated, then the overall mean that must be achieved to ensure (with a prespecified confidence level) that a predetermined number of samples violate the limit can be specified. For example, if the standard deviation in soil permeability is 10^{-8} cm/s and it would be undesirable to have more than 2 percent of the samples with permeability measurements greater than 10^{-7} cm/s, then the acceptable mean level would be $10^{-7} - 2.05 (10^{-8}) = 7.95 \times 10^{-8}$ cm/s. If, however, it is deemed satisfactory for 0.2 percent of the permeabilities to exceed the specification of 10^{-7} cm/s, then the acceptable mean level would be

$10^{-7} - 2.88 (10^{-8}) = 7.12 \times 10^{-8}$ cm/s. Using these means along with considerations of the acceptability of judging an unacceptable material or process as acceptable or rejecting an acceptable material as unacceptable (type II and I errors, respectively, in statistical terminology), a required sample size can be estimated (Burr, 1976).

2.4.3.2.2 Sequential sampling plan--All of the sampling plans and sample size estimates discussed so far (with the possible exception of sample supplementation to reduce variance of sample estimates) assume that the sample size or sampling frequency will be determined prior to initiation of the sampling program (i.e., the data from the sample will not influence these estimates). The purpose of sequential sampling plans is to obtain sufficient data for evaluation of quality with fewer sampling units on the average than that required by even the best single sample plans. The general approach is to determine after selection and testing of each sample unit if an evaluation can be performed with acceptable precision. If so, the sampling process is terminated; if not, another sample unit is selected. Hence, if the test results are very uniform and at the levels originally hypothesized (or desired) or if the results deviate markedly from the hypothesized (or desired) levels, a decision to accept or reject the material or process can be made with few sample units. If, however, the data are highly variable and reasonably close to the rejection criteria, a larger sample will be required before a decision can be made. Hence the sample size is a variable in this type of sampling design.

2.4.4 Treatment of Outliers

Occasionally, in a supposedly homogeneous sample, one of the test values appears to deviate markedly from the remainder of the sample. Such a value is called an outlier. Rules for rejection of outliers are based on confidence level criteria. Standard practice for dealing with outlying observations are contained in ASTM (1985b) E 178. This practice may be applied only to random, statistically evaluated samples. According to ASTM E178, two alternative explanations for outliers are of interest:

- An outlying observation may be an extreme manifestation of the random variability inherent in the data. In this case,

the value should be retained and processed with the other observations in the sample.

- An outlying observation may result from gross deviation from the test procedure or an error in calculating or recording the numerical value. In this case, the outlier may be rejected or not, if used in the subsequent analyses, the outlying values will be recognized as being from a different population than the other sample values.

ASTM E178 provides statistical rules that lead the investigator to look for causes of outliers and decide which of the above alternatives apply so that the most appropriate action may be taken in further data analysis. The procedures used are too extensive to quote in this document, and the reader is referred to ASTM (1985b).

2.4.5 Corrective Measures Implementation

In the event of noncompliance, when material or work is rejected because observations or tests indicate that it does not meet the design criteria, plans, and specifications, corrective measures must be implemented. For material subject to 100-percent inspection, substandard material is simply rejected. When workmanship subject to 100-percent testing is rejected (e.g., synthetic membrane seams), it must be redone until it meets specifications. For workmanship in question because of an inspector's observations, additional testing of the component may be necessary prior to rejecting the block of work and specifying corrective measures.

In general, the rejection of any material or workmanship on the basis of test results may be a result of deficiencies in the work or material or errors in the test results. If the probability of systematic error in the test methods and the actual variability of the measured parameters are known and statistical sampling methods are used, then a degree of confidence in the test results, based on the number of tests per block of work or material, can be estimated. However, this does not consider the possibility of random error that may be introduced by such factors as poorly conducted tests or mistakes in recording test results. Because the cost of additional testing is considerably less than implementing most corrective measures, if a block of work is rejected on the basis of a failed test or series of tests, implementing the following sequence of corrective measures may be prudent (adapted from Selig, 1982):

- Rerun the field test(s). If the second test passes, an error in the first test may be assumed and the work or material may be accepted.
- If the second test fails, require the contractor to attempt to rework the material in place to bring it up to specifications, and retest.
- If the work still fails, remove the material and replace it, testing the new material to ensure compliance.

For any facility component, the actual physical means of corrective measures, in the case of noncompliance, is a combined design and construction function. Both of the latter topics are beyond the scope of this document.

2.4.6 Control Charts

For some materials or processes it may be necessary or desirable to maintain records of quality over time. For example, it may be necessary to assess the grain size of truck loads of incoming soils used in preparing the liner. Assuming that the loads are relatively homogeneous (there are no major differences in soil types or moisture content among the loads) a control chart approach might be used. A systematic sampling design could be used to select incoming truck loads for analysis and the test results would be plotted against time. These types of plots provide a means to keep track of the incoming materials so that appropriate action may be taken whenever it is indicated (actions to be taken in response to deviations from the norm should be specified by the design engineer). For some material or properties, deviations in quality in either direction may be important (such as soil moisture content); for others, deviations in only one direction will be of concern (such as soil permeability).

One of the fundamental questions of this approach is: What is an abnormal test result? Upper and lower limits of acceptability about the norm or mean of the test results can be established by assuming that the measurements are normally distributed and setting limits that will include a predetermined proportion of the measurements (usually 90 or 95 percent) or by setting them at some predetermined level of acceptability (such as a maximum of 10^{-7} level of permeability for soils used as liner material).

For those measurements where little is known concerning natural variability and there is no sound basis for setting a level of acceptability, the test results from experimental sites (e.g., test fills) could be used to establish a norm and usual variation that could be used for setting up the control chart.

It will likely be advisable to revise the control chart limits as tests are performed on the disposal site; these changes should only be done with the concurrence of the CQA officer and the design engineer. All measurements that fall outside the established limits should be referred to the CQA officer, who will attempt to identify the cause for deviation and the appropriate action to rectify the problem; specific responses to deviation should be specified by the design engineer. The usual practice in quality control statistics is to record summary results (means, standard deviations, or ranges) of multiple measurements for each sample, where each sample consists of a series of subunits; an example of this approach might be used in a design where large soil samples are selected from a liner by a grid system and multiple measurements of soil density are performed for each grid section. For land disposal sites, however, it will probably be more common to record individual measurements on the control chart (Burr, 1976). The sample size/frequency (number of sample unit or sampling interval), sampling unit (truck load, grid section of liner, etc.), and acceptance criteria must be determined by the design engineer and will depend on the specific goal of an assessment, the site-specific characteristics of a particular material or process to be evaluated, and the expected variability of the test data.

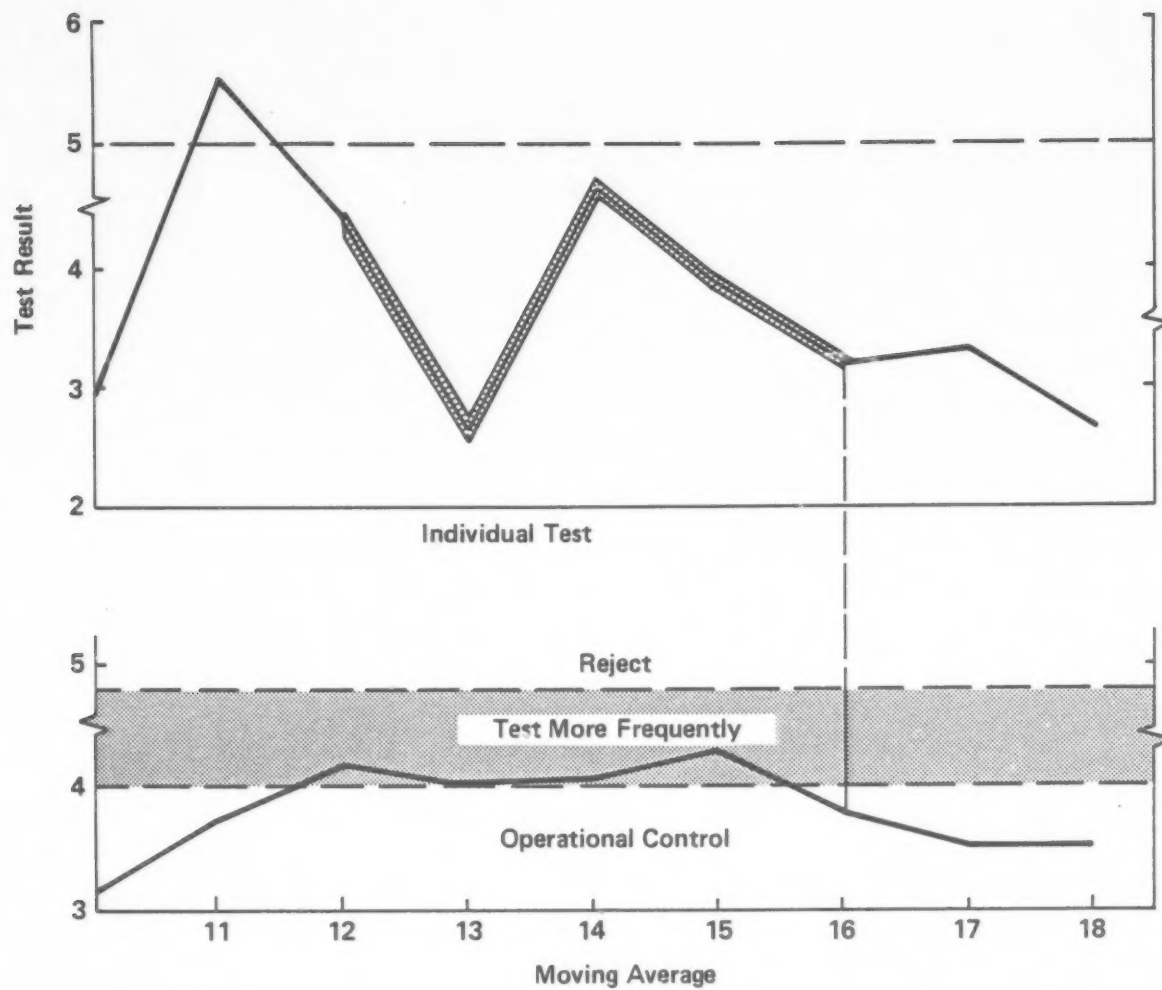
Control charts can be used to monitor the quality of material or workmanship over time, providing a useful record of the performance of a construction contractor or material variability as the facility is being constructed. For example, the owner/operator, design engineer, or CQA officer may use these charts to detect trends in workmanship quality that may not be apparent when comparing the results of individual tests. With the use of control charts, declines in workmanship quality can be correlated with potential causes (e.g., weather conditions) and appropriate corrective measures (e.g., changes in operating procedures, additional training pro-

grams, or more frequent testing) may be implemented in a timely fashion. Another example would be using control charts to detect increases in material variability that may require more frequent testing of the incoming material.

Properly maintained control charts can provide an immediate review of the quality of a block of material or workmanship (Beaton, 1968). They provide a convenient and concise means of documenting construction quality and may serve to summarize a great volume of test reports and other records, speeding up review of test records and acceptance of a block of completed work.

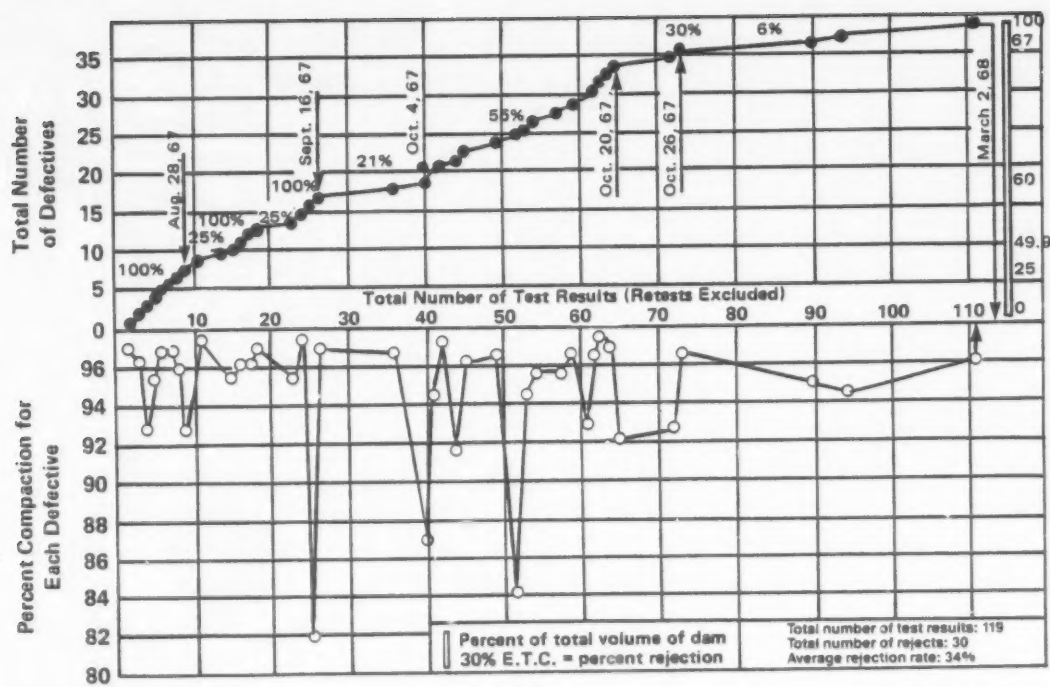
An example of a control chart is presented in Figure 2-3. In the upper graph, individual test results for a block of material are plotted in chronological order. In the lower graph, a moving average of the test results is plotted on a graph. If the average test results are in the shaded area (approaching the rejection level), more frequent testing is required to accept the lot. Below the shaded area, the lot is accepted; above it, it is rejected. If statistical sampling methods are used, the acceptance/rejection levels and the levels requiring more testing may be determined by statistical methods, as described earlier in this section.

Kotzias and Stamatopoulos (1975) used three types of control charts with judgment sampling methods to evaluate construction quality for an earthen dam. Simple quality control charts were used to evaluate day-to-day construction performance. These charts plotted daily averages and ranges of test results over the course of the construction period and are valuable chronological records, but are not formal control charts. Rejection charts (Figure 2-4) plot the total number of rejected tests cumulatively and the magnitude of each rejected result against the total number of test results (retests excluded). These charts reveal the rejection rate and the severity of defects in the rejected material (compacted earthfill). Finally, frequency diagrams (Figure 2-5) were plotted for whole components or for sampling blocks. These diagrams were presented in pairs, i.e., defects included, retests excluded (before remedial action), and defects excluded, retests included (as accepted). These charts are bar diagrams plotting number of test results against test results (Figure 2-5). Evaluated jointly with rejection charts (Figure 2-4), they provide a way of determining the overall importance of defects and remedial measures.



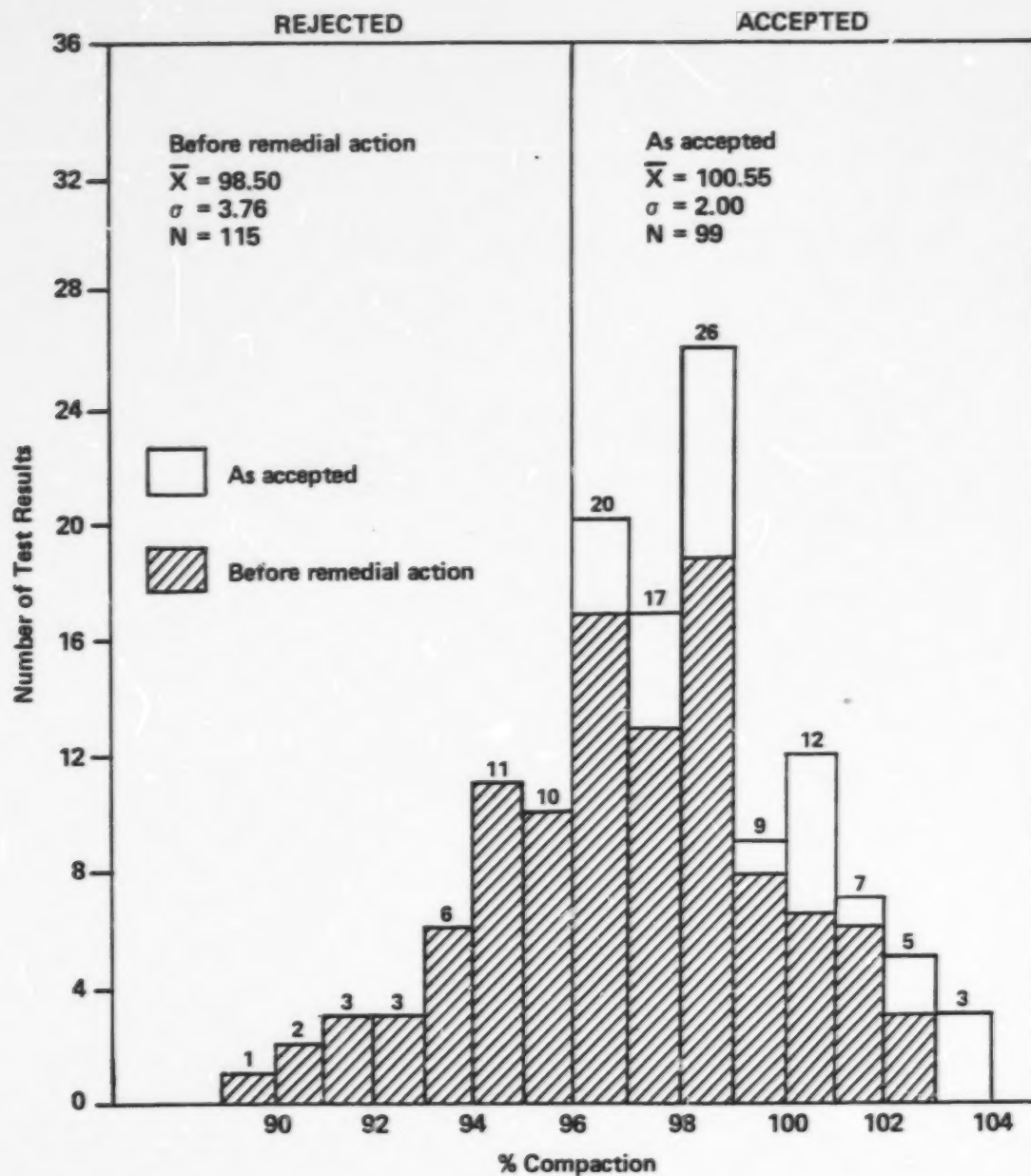
(Beaton, 1968)

Figure 2-3. Control charts, individual and moving average.



(Beaton, 1968)

Figure 2-4. Rejection chart: density measurements for dam core compaction control.



From Kotzias and Stamatopoulos, 1975

Figure 2-5. Frequency diagram: density measurements for dam core compaction control.

Although control charts may be used with either judgment or statistical sampling, when used with judgment methods they reflect the bias inherent in the judgment sampling. Thus, the "as accepted" frequency diagrams may not accurately represent the quality of the completed work for judgment sampling, but will for a sampling plan determined by statistical methods.

For more information concerning the use of control charts see standard texts concerning quality control such as Duncan (1959), Burr (1976), or Grant (1964).

2.5 DOCUMENTATION

The ultimate value of a CQA plan depends to a large extent on recognition of all of the construction activities that should be inspected and the assignments of responsibilities to CQA personnel for the inspection of each activity. This is most effectively accomplished by documenting CQA activities and should be addressed as the fifth element of the CQA plan. The CQA personnel will be reminded of the items to be inspected, and will note, through required descriptive remarks, data sheets, and checklists signed by them, that the inspection activities have been accomplished.

2.5.1 Daily Recordkeeping

Standard daily reporting procedures should include preparation of a summary report with supporting inspection data sheets and, when appropriate, problem identification and corrective measures reports.

2.5.1.1 Daily Summary Report--

A summary report should be prepared daily by the CQA officer. This report provides the chronologic framework for identifying and recording all other reports. At a minimum, the summary reports should include the following information (Spigolon and Kelley, 1984):

- Unique identifying sheet number for cross-referencing and document control
- Date, project name, location, and other identification
- Data on weather conditions
- Reports on any meetings held and their results

- Unit processes, and locations, of construction underway during the time frame of the daily summary report
- Equipment and personnel being worked in each unit process, including subcontractors
- Descriptions of areas or units of work (blocks) being inspected and documented
- Description of offsite materials received, including any quality verification (vendor certification) documentation
- Calibrations, or recalibrations, of test equipment, including actions taken as a result of recalibration
- Decisions made regarding approval of units of material or of work (blocks), and/or corrective actions to be taken in instances of substandard quality
- Unique identifying sheet numbers of inspection data sheets and/or problem reporting and corrective measures reports used to substantiate the decisions described in the preceding item
- Signature of the CQA officer.

Items above may be formulated into site-specific checklists and data sheets so that details are not overlooked.

2.5.1.2 Inspection Data Sheets--

All observations, and field and/or laboratory tests, should be recorded on an inspection data sheet. Required data to be addressed for most of the standardized test methods are included in the pertinent AASHTO (1983) and ASTM (1985a) Standards. Examples of field and/or laboratory test data sheets are given in Department of the Army (1970, 1971) manuals and in Spigolon and Kelley (1984).

Because of their nonspecific nature, no standard format can be given for data sheets to record observations. Recorded observations may take the form of notes, charts, sketches, photographs, or any combination of these. Where possible, a checklist may be useful to ensure that no pertinent factors of a specific observation are overlooked.

At a minimum, the inspection data sheets should include the following information (Spigolon and Kelly, 1984):

- Unique identifying sheet number for cross-referencing and document control
- Description or title of the inspection activity
- Location of the inspection activity or location from which the sample increment was obtained
- Type of inspection activity; procedure used (reference to standard method when appropriate)
- Recorded observation or test data, with all necessary calculations
- Results of the inspection activity; comparison with specification requirements
- Personnel involved in the inspection activity
- Signature of the appropriate inspection staff member and concurrence by the CQA officer.

Items above may be formulated into site-specific checklists and data sheets so that details are not overlooked.

2.5.1.3 Problem Identification and Corrective Measures Reports--

A problem is defined herein as material or workmanship that does not meet the design criteria, plans, and specifications. Problem Identification and Corrective Measures Reports should be cross-referenced to specific inspection data sheets where the problem was identified. At a minimum, they should include the following information:

- Unique identifying sheet number for cross-referencing and document control
- Detailed description of the problem
- Location of the problem
- Probable cause
- How and when the problem was located (reference to inspection data sheets)
- Estimation of how long problem has existed
- Suggested corrective measure

- Documentation of correction (reference to inspection data sheets)
- Final results
- Suggested methods to prevent similar problems
- Signature of the appropriate inspection staff member and concurrence by the CQA officer.

In some cases, not all of the above information will be available or obtainable. However, when available, such efforts to document problems could help to avoid similar problems in the future.

The CQA officer should be made aware of any significant recurring non-conformances. The CQA officer will then determine the cause of the nonconformance and recommend appropriate changes to prevent recurrence. When this type of evaluation is made, the results should be documented by the inspection staff in a brief report containing the supporting problem identification and corrective measures reports.

Upon receiving the CQA officer's written concurrence, copies of the report should be sent to the design engineer and the facility owner/operator for their comments and acceptance. These reports should not be submitted to the permitting agency unless they have been specifically requested. However, a summary of all data sheets along with final testing results and inspector certification of the facility may be required by the permitting agency upon completion of construction.

2.5.2 Photographic Reporting Data Sheets

Photographic reporting data sheets also may prove useful. Such data sheets could be cross-referenced or appended to inspection data sheets and/or problem identification and corrective measures reports. At a minimum, photographic reporting data sheets should include the following information:

- A unique identifying number on data sheets and photographs for cross-referencing and document control
- The date, time, and location where the photograph was taken and weather conditions
- The size, scale, and orientation of the subject matter photographed

- Location and description of the work
- The purpose of the photograph
- Signature of the photographer and CQA officer.

These photographs will serve as a pictorial record of work progress, problems, and corrective measures. They should be kept in a permanent protective file in the chronological order in which they were taken. The basic file should contain color prints; negatives should be stored in a separate file in chronological order.

A video recording of problem areas and/or conditions and of the completed installation of each soil component also may prove useful.

2.5.3 Block Evaluation Reports

Within each inspection block, there may be several quality characteristics, or parameters, that are specified to be observed or tested, each by a different observation or test, with the observations and/or tests recorded on different data sheets. At the completion of each block, these data sheets should be organized into a block evaluation report. These block evaluation reports may then be used to summarize all of the site construction activities.

Block evaluation reports should be prepared by the CQA officer and, at a minimum, include the following information (Spigolon and Kelley, 1984):

- Unique identifying sheet number for cross-referencing and document control
- Description of block (use project coordinate system to identify areas, and appropriate identifiers for other units of materials or work)
- Quality characteristic being evaluated; references to design criteria, plans, and specifications
- Sampling requirements for the inspected block and how they were established
- Sample item locations (describe by project coordinates or by a location sketch on the reverse of the sheet)
- Inspections made (define procedure by name or other identifier; give unique identifying sheet number for inspection data sheets)

- Summary of inspection results (give block average and, if available, the standard deviation for each quality characteristic)
- Define acceptance criteria (compare block inspection data with design specification requirements; indicate compliance or noncompliance; in the event of noncompliance, identify documentation that gives reasons for acceptance outside of the specified design)
- Signature of the CQA officer.

2.5.4 Design Engineer's Acceptance of Completed Components

All daily inspection summary reports, inspection data sheets, problem identification and corrective measures reports, and block evaluation reports should be reviewed by the CQA officer and then submitted to the design engineer. The reports should be evaluated and analyzed for internal consistency and for consistency with similar work. Timely submittal of these documents will permit errors, inconsistencies, and other problems to be detected and corrected as they occur, when corrective measures are easiest.

The design engineer should assemble and summarize the above information into a periodic Design Acceptance Report. The reports should indicate that the materials and construction processes comply with design specifications and permit requirements. These reports should be included in project records and, if requested, submitted to the permitting agency.

2.5.5 Final Documentation

At the completion of the project, the facility owner/operator should submit a final report to the permitting agency. This report should include all of the daily inspection summary reports, inspection data sheets, problem identification and corrective measures reports, block evaluation reports, photographic reporting data sheets, design engineers' acceptance reports, deviations from design and material specifications (with justifying documentation), and as-built drawings. This document should be prepared and certified correct by the CQA officer and included as part of the CQA plan documentation.

2.5.5.1 Responsibility and Authority--

The final documentation should reemphasize that areas of responsibility and lines of authority were clearly defined, understood, and accepted by all parties involved in the project. Signatures of the facility owner/operator, design engineer, CQA officer and construction contractor should be included as confirmation that each party understood and accepted the areas of responsibility and lines of authority and performed their function(s) in accordance with the CQA plan.

2.5.5.2 Relationship to Permitting Agencies--

Final documentation submitted to the permitting agency as part of the CQA plan documentation does not sanction the CQA plan as a guarantee of facility construction and performance. Rather, the primary purpose of the final documentation is to improve confidence in the constructed facility through written evidence that the CQA plan was implemented as proposed and that the construction proceeded in accordance with design criteria, plans, and specifications.

2.5.6 Storage of Records

During the construction of a hazardous waste land disposal facility, the CQA officer should be responsible for the facility construction records. This includes the originals of all the data sheets, reports, the design engineer's acceptance of completed components reports, and facility drawings. With the CQA officer in charge of the facility construction records, any documentation problems should be noted and corrected quickly. Once facility construction is complete, the document originals should be stored by the owner/operator in a manner that will allow for easy access. An additional copy should also be kept at the facility if this is in a different location from the owner/operator's files. A final copy should be kept by the permitting agency in a publicly acknowledged repository.

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APPENDIX A. INSPECTION METHODS USED DURING THE CONSTRUCTION OF HAZARDOUS
WASTE DISPOSAL FACILITIES

Facility component	Factors to be inspected	Inspection methods	Test method reference
Foundation	Removal of unsuitable materials	Observation	NA
	Proof rolling of subgrade	Observation	NA
	Filling of fissures or voids	Observation	NA
	Compaction of soil backfill	(See low-permeability soil liner component)	
	Surface finishing/compaction	Observation	NA
	Sterilization	Supplier's certification and observation	NA
	Slope	Surveying	NA
	Depth of excavation	Surveying	NA
	Seepage	Observation	NA
	Soil type (index properties)	Visual-manual procedure Particle size analysis Atterberg limits Soil classification	ASTM D2488-84 ASTM D422-63 ASTM D4318-84 ASTM D2487-83
	Cohesive soil consistency (field)	Penetration tests Field vane shear test Hand penetrometer Handheld torvane Field expedient unconfined compression	ASTM D3441-79 ASTM D2573-72 Horslev, 1943 Lanz, 1968 TM 5-530 (U.S. Dept. of Army, 1971)
	Strength (laboratory)	Unconfined compressive strength Triaxial compression	ASTM D2166-66 ASTM D2850-82
Dikes	Dike slopes	Surveying	NA
	Dike dimensions	Surveying; observations	NA
	Compacted soil	(See foundation component)	
	Drainage system	(See leachate collection system component)	
	Erosion control measures	(See cover system component)	

(continued)

APPENDIX A (continued)

Facility component	Factors to be inspected	Inspection methods	Test method reference
Low-permeability soil liner	Coverage	Observation	NA
	Thickness	Surveying; measurement	NA
	Clod size	Observation	NA
	Tying together of lifts	Observation	NA
	Slope	Surveying	
	Installation of protective cover	Observation	NA
	Soil type (index properties)	Visual-manual procedure Particle size analysis Atterberg limits Soil classification	ASTM D2488-84 ASTM D422-63 ASTM D4318-84 ASTM D2487-83
	Moisture content	Oven-dry method Nuclear method Calcium carbide (speedy) Frying pan (alcohol or gas burner)	ASTM D2216-80 ASTM D3017-78 AASHTO T217 Spigolon & Kelley (1984)
	In-place density	Nuclear methods Sand cone Rubber balloon Drive cylinder	ASTM D2922-81 ASTM D1556-82 ASTM D2167-84 ASTM D2937-83
	Moisture-density relations	Standard proctor Modified proctor	ASTM D698-78 ASTM D1557-78
	Strength (laboratory)	Unconfined compressive strength Triaxial compression	ASTM D2166-66 ASTM D2850-82
	Cohesive soil consistency (field)	Penetration tests Field vane shear test Hand penetrometer Handheld torvane Field expedient unconfined compression	ASTM D3441-79 ASTM D2573-72 Horslev, 1943 Lanz, 1968 TM 5-530 (U.S. Dept. of Army, 1971)
	Permeability (laboratory)	Fixed wall Flexible wall-	EPA, 1983. SW-870 Daniel et al., 1984 Daniel et al., 1985
	Permeability (field)	Large diameter single-ring infiltrometer Sai-Anderson infiltrometer	Day and Daniel, 1985 Anderson et al., 1984

(continued)

APPENDIX A (continued)

Facility component	Factors to be inspected	Inspection methods	Test method reference
Flexible membrane liners	Susceptibility to frost damage	Susceptibility classification	Chamberlin, 1981
	Volume change	Consolidometer (undisturbed or remolded sample)	Holtz, 1965
	Thickness	Thickness of unreinforced plastic sheeting (paragraph 8.1.3, deadweight method--specifications for nonrigid vinyl chloride plastic sheeting)	ASTM D1593
		Thickness of reinforced plastic sheeting (testing coated fabrics)	ASTM D751
	Tensile properties	Tensile properties of rigid thick plastic sheeting (standard method test for tensile properties of plastics)	ASTM D638
		Tensile properties of reinforced plastic sheeting (Grab method A--testing coated fabrics)	ASTM D751
		Tensile properties of thin plastic sheeting	ASTM D882
		Tear strength of reinforced plastic sheeting (modified tongue tear method B--testing coated fabrics)	ASTM D751
	Tear strength	Tear strength of plastic sheeting (Die C--test method for initial tear resistance of plastic film and sheeting).	ASTM D1004
	Bonding materials	Manufacturer's certification	NA
	Bonding equipment	Manufacturer's certification	NA
	Handling and storage	Observation	NA

(continued)

APPENDIX A (continued)

Facility component	Factors to be inspected	Inspection methods	Test method reference
	Seaming	Ply adhesion of reinforced synthetic membranes, bonded seam strength in peel (machine method, Type A test methods for rubber properties, adhesion to flexible substrate)	ASTM D413
		Bonded seam strength in shear of reinforced plastic sheeting (modified grab method A--testing coated fabrics)	ASTM D751
		Bonded seam strength in shear of unreinforced plastic sheeting (modified)	ASTM D3083
	Sealing around penetrations	Observation	NA
	Anchoring	Observation	NA
	Coverage	Observation	NA
	Installation of upper bedding layer	Observation	NA
	Leachate collection system		
	Granular drainage and filter layers	Thickness	Surveying; measurement NA
		Coverage	Observation NA
	Soil type	Visual-manual procedure	ASTM D2488-84
		Particle size analysis	ASTM D422-63
		Soil classification	ASTM D2487-83
	Density	Nuclear methods	ASTM D2922-81
		Sand cone	ASTM D1556-82
		Rubber balloon	ASTM D2167-84
	Permeability (laboratory)	Constant head	ASTM D2434-38
Synthetic drainage and filter layers	Material type	Manufacturer's certification	NA
	Handling and storage	Observation	NA
	Coverage	Observation	NA

(continued)

APPENDIX A (continued)

Facility component	Factors to be inspected	Inspection methods	Test method reference
• Pipes	Overlap	Observation	NA
	Temporary anchoring	Observation	NA
	Folds and wrinkles	Observation	NA
	Geotextile properties	Tensile strength	Horz (1984)
		Puncture or burst resistance	Horz (1984)
		Tear resistance	Horz (1984)
		Flexibility	Horz (1984)
		Outdoor weatherability	Horz (1984)
		Short-term chemical resistance	Horz (1984)
		Fabric permeability	Horz (1984)
		Percent open area	Horz (1984)
	Material type	Manufacturer's certification	NA
	Handling and storage	Observation	NA
	Location	Surveying	NA
	Layout	Surveying	NA
	Orientation of perforations	Observation	NA
	Jointing		
• Cast-in-place concrete structures	• Solid pressure pipe	Hydrostatic pressure test	Section 4, AMWA C600-82
	• Perforated pipe	Observation	NA
	Sampling	Sampling fresh concrete	ASTM C172
	Consistency	Slump of portland cement concrete	ASTM C143
	Compressive strength	Making, curing, and testing concrete specimens	ASTM C31
	Air content	Pressure method	ASTM C231
	Unit weight, yield, and air content	Gravimetric method	ASTM C138
	Form work inspection	Observation	NA

(continued)

APPENDIX A (continued)

Facility component	Factors to be inspected	Inspection methods	Test method reference
• Electrical and mechanical equipment	Equipment type	Manufacturer's certification	NA
	Material type	Manufacturer's certification	NA
	Operation	As per manufacturer's instructions	NA
	Electrical connections	As per manufacturer's instructions	NA
	Insulation	As per manufacturer's instructions	NA
	Grounding	As per manufacturer's instructions	NA
Cover system			
• Cover foundation	Waste placement records/ waste placement process	Observation	NA
	Soil backfill	(See foundation component)	
• Low-permeability soil barrier	(See low-permeability soil liner component)		
• Flexible membrane barrier	(See flexible membrane liner component)		
• Bedding layer	(See flexible membrane liner component)		
• Drainage and gas venting layers	(See leachate collection system component)		
• Topsoil and vegetation (erosion control measures)	Thickness	Surveying	NA
	Slope	Surveying	NA
	Coverage	Observations	NA
	Nutrient content	Various procedures	Page, 1982
	Soil pH	Soil pH; lime requirement	Page, 1982
	Soil type; moisture content	(See low-permeability soil liner component)	
	Vegetation type	Supplier's certification; observations	NA
	Seeding time	Supplier's recommendations; observations	NA